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of the

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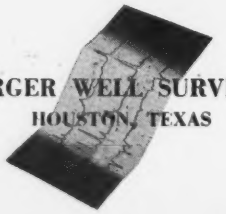

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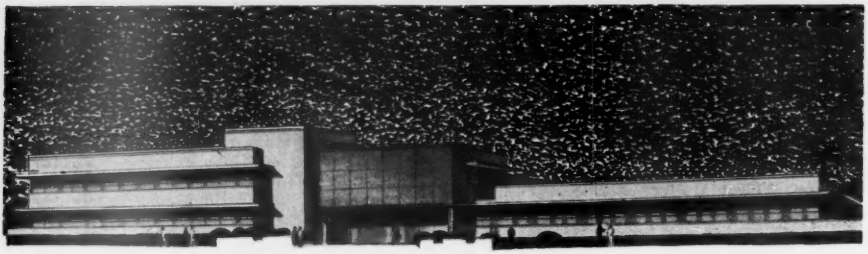

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FEBRUARY, 1949

SUBSURFACE CROSS SECTIONS FROM MARION COUNTY KANSAS, TO OSAGE COUNTY, OKLAHOMA[1]

L. H. LUKERT[2]
Tulsa, Oklahoma

ABSTRACT

The author discusses the results of a subsurface stratigraphic investigation based on cross-sectional studies in northeastern and north-central Oklahoma and south-central Kansas. Two continuous cross sections are presented. One extends from a well in Sec. 36, T. 19 S., R. 1 E., Marion County, Kansas, southward across the state line in R. 2 E., Kansas, and continues to a well in Sec. 8, T. 23 N., R. 3 W., Garfield County, Oklahoma. From that point the other section extends eastward to a well in Sec. 30, T. 22 N., R. 8 E., Osage County, Oklahoma. The combined length of the cross sections is approximately 175 miles, and 33 wells are used.

The area is on, or downdip from, the belt of outcrop of Lower Permian and Upper and Middle Pennsylvanian rocks, whose strike is slightly east of north and whose regional dip is toward the west. The area contains the transition between deposits of the northern Mid-Continent basin in which relatively thin but persistent limestones are a dominant feature and deposits of southern Oklahoma where clastic sediments strongly predominate. Rocks penetrated in wells used in the cross sections are Paleozoic in age and they are classified into Permian, Pennsylvanian, Mississippian, Silurian-Devonian, and Ordovician systems. The geologic section studied extends downward from the Herington limestone which is the uppermost member of the Permian Wolfcampian series. Although particular attention is given in this study to rocks in the Pennsylvanian Virgilian and Missourian series, the correlations of the older beds are also shown. Hundreds of wells have been drilled in the area which provide ample information for detail subsurface correlation studies. Since petroleum geologists have worked in this area for a long time, many subsurface correlations have been established. The correlations resulting from the present study are based on electrical logs and sample studies. Several published and unpublished surface sections and a field examination of outcrops were helpful in tracing some of the exposed beds underground.

The cross sections show that beds and formations can be traced throughout the area. Subsurface rocks in the middle and lower Virgilian and Missourian series, however, are not so persistent and they

[1] Read by title before the Association at Denver, Colorado, April 26–29, 1948. Presented before the Tulsa, Oklahoma City, and Shawnee geological societies in April, June, and December, 1947. Manuscript received, September 22, 1948.

[2] Division geologist, The Texas Company. The writer thanks The Texas Company for permission to publish. He desires to thank Malcolm C. Oakes, geologist, Oklahoma Geological Survey, for discussions of problems of the surface geology and for visits in the field. He is grateful to Robert F. Walters for suggestions concerning the illustrations and for critical review of the manuscript. Robert H. Dott and Hugh D. Miser also kindly reviewed and criticized the manuscript. Helpful suggestions were made by V. C. Scott, Charles Ryniker, E. Floyd Miller, and G. S. Dillé. The writer extends his gratitude to these and others who helped in any way. Credit is due Eleanor K. Lee and Paul Allen who helped prepare the illustrations. Fusulinid determinations were made by Erik K. Waering of Helmerich and Payne, Inc.

present problems in correlation. Because of lithologic changes the same classification can not be used in Osage County, Oklahoma, that is used in Kansas for this interval of rocks. Similar conditions have been found and reported by field geologists for the equivalent surface rocks. In southern Osage County, Oklahoma, some of the Missourian beds were traced from the surface into the underground by well samples. This study shows that the Hogshooter, Dewey, Avant, and Wildhorse limestones and the Cottage Grove sandstone can be traced readily underground in the area of the cross sections. The data indicate that the Cottage Grove sandstone is equivalent to the "Mussellem" sand (of Bass) which is also referred to by some geologists as "Layton," "Osage Layton," "Layton of Ponca City," or "Peoples." It is further concluded that the Avant and Dewey limestones are stratigraphically lower than the zone commonly called "Avant," "Avant-Dewey," or "Dewey" in the subsurface.

Introduction

Petroleum geologists in Oklahoma have long recognized the need for a closer study of the correlation of subsurface formations in the Lower Permian and Penn-

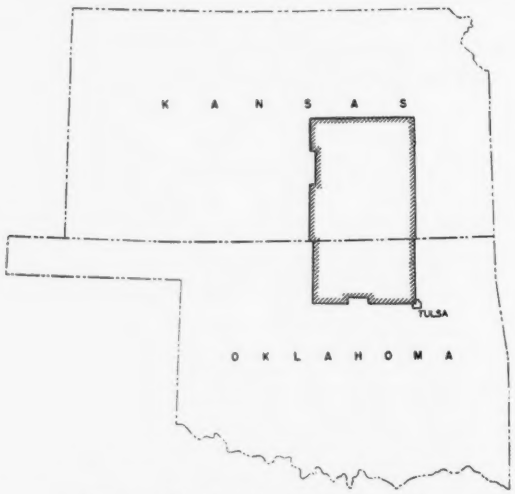


Fig. 1.—Index map showing area studied.

sylvanian rocks penetrated in test wells for oil and gas. This paper summarizes the results of a subsurface investigation in northeastern and north-central Oklahoma and south-central Kansas based on electrical-log cross sections and microscopic examination of well cuttings. The area is on, or downdip from, the belt of outcropping rocks of Lower Permian and Upper and Middle Pennsylvanian age. Hundreds of wells have been drilled in this area. There is thus ample surface and subsurface information for detailed subsurface correlation studies. The mass of data available in the more densely drilled area permits rather definite identification of beds, and allows for reasonable correlation into the sparsely drilled and less known areas. The investigation seems timely in view of the recent increased drilling activity in western Oklahoma and southwestern Kansas. It was originally intended to confine the study to northern Oklahoma, but when problems of cor-

relation were encountered in the Upper Pennsylvanian it became advisable to extend the investigation northward into Kansas where the section of rocks in question is more regular and where the problems could be settled more readily. Many of the Kansas beds can be traced a considerable distance southward into Oklahoma along their regional strike. The Oklahoma subsurface section in Grant, Kay, Garfield, and Noble counties is more similar to that of Kansas than to the section of rocks exposed updip in southern Osage County.

Rocks encountered in the wells used in the cross sections range in age from Permian to Ordovician. In this study, the section of rocks from the top of the Herington limestone, the uppermost member of the Wolfcampian series of the Permian, to the base of the Missourian series of the Pennsylvanian, has been of primary concern. However, in order to add to the usefulness of the cross sections the rocks underlying the Pennsylvanian formations have been included.

Location of Cross Sections

The area traversed by the cross sections is in southeastern Kansas and northeastern and north-central Oklahoma (Fig. 1). Thirty-three wells (Table I) were selected to form the two continuous cross sections shown in Figure 2. Cross section *AB* (Pl. I) extends from well No. 1 in the SW. $\frac{1}{4}$, NW. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 36, T. 19 S., R. 1 E., Marion County, Kansas, to well No. 19 in the NW. $\frac{1}{4}$, NW. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 8, T. 23 N., R. 3 W., Garfield County, Oklahoma. The north end of the cross section, in Marion County, Kansas, permits comparisons with a previously published subsurface cross section by Betty Kellet.[3] Well No. 1 on the writer's cross section may be compared with Kellet's well No. 82 as the two wells are less than $1\frac{1}{2}$ miles apart. Cross section *BC* (Pl. II) extends from well No. 19 to well No. 33 in the NE. $\frac{1}{4}$, NW. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 30, T. 22 N., R. 8 E., Osage County, Oklahoma.

As this investigation is primarily a stratigraphic study, the wells in cross section *AB* are aligned vertically so that the base of the Plattsmouth limestone member of the Oread limestone forms an approximate horizontal plane. In cross section *BC* all wells are aligned so that the base of the Elgin sandstone forms an approximately horizontal plane. Horizontal distances between wells are not drawn to scale in either of the two sections.

Methods of Investigation

Studies in subsurface stratigraphy in this area have been made by geologists for many years. As a result of these studies, many subsurface correlations have been long established and are accepted in this work. Correlations based on the present work were extended underground primarily with the aid of electrical logs which have come to be an important tool in stratigraphic studies. Few geologists

[3] Betty Kellet, "Geologic Cross Section from Western Missouri to Western Kansas Showing Correlations of Permian Big Blue Series and Pennsylvanian," *Sixth Annual Field Conference, Kansas Geol. Society, October, 1932.*

TABLE I

List of Wells Used in Cross Sections

Operator	Farm Name	Well No.	Location	County	Surface Elevation above Sea-Level (Feet)	Total Depth Drilled (Feet)	Total Depth Electrical Log (Feet)	Remarks
			KANSAS					
1. Texas Company	M. Weinbrenner	1	SW NW NW Sec. 36, T. 19S., R. 1E.	Marion	1,500	3,350	3,350	Plugged
2. Texas Company	B. Schmidt	1	NE SW SW 31 20 3	Marion	1,443	3,150	3,150	Plugged
3. Texas Company	B. W. Blackford	1	NE NE NE 24 25 2	Sedgwick	1,355	3,375	3,378	Plugged
4. Texas Company	H. S. Stollei	1	SE SW SW 22 26 2	Sedgwick	1,405	2,927	2,915	Pumped 31 bbls. oil in 24 hrs. from 2,925–27 feet
5. Texas Company	M. D. Devine	1	NE NE SE 11 28 2	Sedgwick	1,349	3,350	3,350	Plugged
6. Barnsdall Oil Co.	P. L. Hatfield	1	SE NW NW 17 29 2	Sedgwick	1,308	3,560	3,551	Plugged
7. R. L. Carnahan	M. C. Parker	1	NE NE SE 7 30 2	Sumner	1,216	3,650	3,648	Plugged
8. Barnett Drlg. Co	John T. Wilson	6	Cen. SE SW 33 31 3	Cowley	1,187	3,208	3,198	Plugged
9. E. S. Adkins	J. G. Lemback	1	SW NW NE 8 33 3	Cowley	1,135	3,512	3,506	Pumped an estimated 70 bbls. oil in 24 hrs. from 3,502–10 feet
10. E. S. Adkins	B. M. Stephens	1	NW NE SW 26 33 3	Cowley	1,143	3,372	3,364	Plugged
11. Texas Company	C. O. Booten	1	NW SW SW 21 34 3	Cowley	1,143	3,850	3,847	Plugged
12. Texas Company	Eva Anderson	1	SW SW NW 11 35 2	Sumner	1,195	3,570	3,573	Flowed 15 bbls. oil and 25 bbls. water in 16 hrs. from 2,776–97 feet
			OKLAHOMA					
13. Shell Oil Co., Inc.	J. McCormack	B-4	App. NW SW SE 21 29N. 1W.	Kay	1,125	3,470	3,460	Plugged
14. Ohio Oil Co.	School Land	2	SW NE SW 16 28 1	Kay	1,048	3,608	3,662	Pumped 55 bbls. oil and 12 bbls. water in 24 hrs. from 3,658–66 feet
15. Barnsdall Oil Co.	Eli Balderson	1	NE SW SE 24 28 3	Grant	1,149	4,821	4,819	Plugged
16. Amerada Petr. Corp.	Ida E. Newkirk	1	NE NE SW 10 26 3	Grant	1,100	5,017	5,010	Plugged
17. Carter Oil Co.	C. A. Staggers	1	C W½ SE NW 4 25 3	Grant	1,001	5,528	5,330	Plugged
18. Fain-Porter Drlg. Co.	G. W. Whitaker	1	NW NW SE 27 24 3	Garfield	997	5,099	5,098	Plugged
19. Helmerich & Payne, Inc.	M. D. LaGrange	1	NW NW NW 8 23 3	Garfield	1,059	5,503	5,487	Plugged
20. Herndon Drlg. Co.	Moore	1	NW NW SE 14 23 3	Garfield	1,019	4,831	4,831	Plugged
21. Ohio Oil Co.	A. Zimmerman	1	NE SE NW 19 23 2	Noble	1,012	4,555	4,555	Plugged
22. Olson Drlg. Co.	L. B. Smith	1	SW SW SE 2 22 2	Noble	1,000	5,253	5,251	Plugged
23. Kingwood Oil Co.	C. A. Bolay	2	SW SE NW 35 23 1	Noble	939	4,675	4,676	Plugged
24. Superior Oil Corp	C. F. Williams	1	NE SW SW 13 22 1E.	Noble	1,012	3,218	3,204	Pumped 61 bbls. oil in 24 hrs. from 3,190–3,218 feet
25. Deep Rock Oil Corp.	R. Schultz	3	C NE SW 9 22 2	Noble	1,001	4,541	4,502	Plugged
26. Magnolia Petr. Co.	E. B. Veronneru	1	SE NE NW 10 22 2	Noble	942	4,455	4,456	Plugged
27. Watchorn Petr. Co.	C. F. Laird	1	C SW SW 2 22 3	Pawnee	1,008	4,232	4,214	Plugged
28. Continental Oil Co.	G F. Feaster	1	SW SW SW 4 22 4	Pawnee	1,037	4,049	4,049	Plugged
29. Continental Oil Co.	Fred Myerdirk	1	SW NE NW 10 22 5	Pawnee	954	3,751	3,763	Plugged
30. Continental Oil Co.	J. E. Morrow	1	NE SE SE 22 22 6	Pawnee	924	3,362	3,362	Plugged
31. Keener Oil & Gas Co.	Hugh Ross	1	SE SE NW 29 22 7	Pawnee	901	3,026	3,027	Plugged
32. A. G. Oliphant	E. M. Franklin	4	NE SW SW 34 22 7	Osage	974	3,017	3,013	Plugged
33. A. G. Oliphant	Tom Carson	2	App. NE NW NW 30 22 8	Osage	948	2,947½	2,925	Produced 2 bbls. oil and 3 bbls. water from 2,944–47½ feet

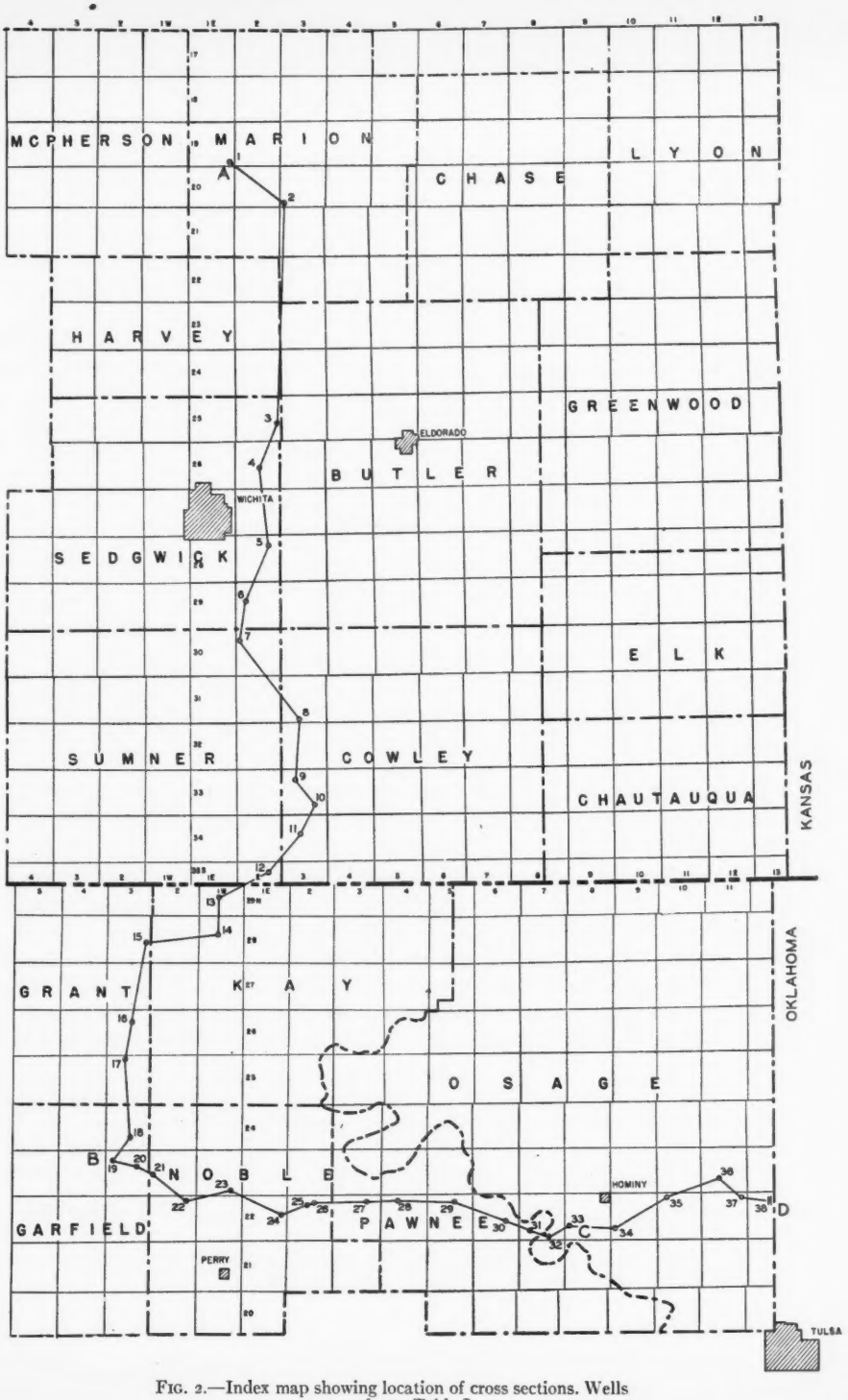


FIG. 2.—Index map showing location of cross sections. Wells 1-33 refer to Table I.

will question the usefulness in this area of the electrical logs for correlation purposes. Electrical logs demonstrate clearly the uniformity of intervals, thickness, and character of beds and formations for several miles. A microscopic examination of drill cuttings now available provided additional information to establish some of the correlations. It is not the intent to describe here the lithologic characteristics of the rocks or rock particles, excepting where such characteristics are specially significant.

In one well (No. 4, cross section *AB*, Pl. I) a radioactivity log was available in addition to the electrical log, and this radioactivity survey showed the position of a thin, highly radioactive shale which can be used as a key bed.

The use and study of several published and unpublished surface sections and field examination of outcrops have helped in tracing some of the exposed beds into the underground.

Stratigraphy

The cross sections traverse an area where rocks of Permian and Pennsylvanian age crop out. The area offers many interesting features for study, because as Moore[4] has said,

> . . . it is this region that shows most clearly the transition between deposits that are characteristic of the more northerly part of the Mid-Continent basin in which relatively thin but very persistent limestones are a dominant feature, and those that occur adjacent to the east-west trending geosynclinal belt of central Arkansas and southern Oklahoma where clastic sediments strongly predominate.

The strike of the surface rocks is slightly east of north and the regional dip is west. The surface section appearing at well No. 33 was adapted from Clark and Cooper,[5] Evans,[6] and Murray.[7]

The surface beds are underlain by rocks of Permian, Pennsylvanian, Mississippian, Silurian-Devonian, and Ordovician age. The study, therefore, deals with Paleozoic sedimentary rocks whose thickness ranges from 3,350 feet in well No. 1, 5,503 feet in well No. 1c, to 2,947½ feet in well No. 33.

The stratigraphic sections at the left of well No. 1 (cross section *AB*, Pl. I), and at the right of well No. 33 (cross section *BC*, Pl. I) follow the nomenclature and classification for the Permian and Pennsylvanian systems in usage by the

[4] R. C. Moore, "Upper Carboniferous Rocks of Southeastern Kansas and Northeastern Oklahoma," *Guide Book Eleventh Annual Field Conference, Kansas Geol. Society* (1937), p. 9.

[5] G. C. Clark and C. L. Cooper, "Kay, Grant, Garfield, and Noble Counties," *Oklahoma Geol. Survey Bull. 40*, Vol. II (July, 1930), p. 69. Section from the top of the Herington limestone to the top of the Fort Riley limestone.

[6] Noel Evans, unpublished section from the top of the Fort Riley limestone to the Bird Creek limestone measured in T. 22 and 23 N.

[7] A. N. Murray, *Guide Book Oklahoma City Geol. Society* (November, 1946), Pl. IX. Section from the top of the Bird Creek Limestone to the top of the Elgin sandstone.

State geological surveys of Kansas and Oklahoma. The Kansas Geological Survey[8] no longer employs the term "Bronson" as a Pennsylvanian group name, but now recognizes the boundaries of the Kansas City group as being from the base of the Plattsburg limestone to the base of the Hertha limestone. Likewise, the name Pleasanton has been revived to replace the term "Bourbon." The subsurface formations and subdivisions of the pre-Pennsylvanian formations, generally agreed on and used by petroleum geologists, are accepted as a basis for pre-Pennsylvanian correlations shown in the cross sections. The subsurface rocks are described in descending order.

PERMIAN SYSTEM

Rocks of Permian age crop out in the west half of the area. In the subsurface the thickness along the line of the cross sections varies from 1,175 feet in well No. 1, to nearly 2,000 feet in well No. 19. An eastward thinning occurs as the beds disappear toward the outcrop. Only the beds in the Wolfcampian series are shown in the cross sections.

WOLFCAMPIAN SERIES

Chase group.—The Chase group includes 350–400 feet of beds between the top of the Herington limestone member of the Nolans limestone and the base of the Wreford limestone. Rocks of this group are present in wells 1–27. The Herington limestone, the Winfield limestone, the Towanda limestone member of the Doyle shale, the Barneston limestone which contains the Fort Riley and Florence limestone members, and the Wreford limestone are identified in the cross sections.

Where these limestones are well developed they are easily differentiated on the electrical logs. The Fort Riley and Florence limestones, in particular, produce characteristic self-potential curves which make them useful in correlation work.

The Winfield, Florence, and Wreford limestones are the prominent chert-bearing beds in the Chase group. The Towanda and Florence limestones have not been identified in the surface section illustrated at well No. 33; but they are well represented in the subsurface from the west-central part of Noble County, Oklahoma, northward into the Kansas subsurface.

Council Grove group.—The Council Grove group ranges in thickness from 330 feet in well No. 1 to 520 feet in well No. 19, and comprises the rocks from the base of the Wreford limestone to the base of the Foraker limestone. The Cottonwood, Grenola, Red Eagle, and Foraker limestones are differentiated in the cross sections. The samples from 720 to 730 feet in well No. 4 contain fusulinids identified as Cottonwood forms.

The cross sections indicate considerable thickening in the Council Grove group in western Cowley County, Kansas, between wells 8 and 11. There the Eskridge

[8] R. C. Moore, personal communication (February 11, 1948).
———, "Classification of Pennsylvanian Rocks in Iowa, Kansas, Missouri, Nebraska, and Northern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 32, No. 11 (November, 1948), pp. 2011–40.

shale, between the Cottonwood and Grenola limestones, thickens southward from 25 feet at well No. 8 to 80 feet at well No. 11.

The Grenola-Foraker limestone zone may be recognized on the electrical logs without much difficulty and this sequence of beds is very useful in correlation work. In well cuttings the Foraker limestone commonly contains large, free fusulinids in abundance. In well No. 22, fusulinids collected from the samples taken at the depth of 1,540–1,550 feet have been identified as Foraker forms. Foraker forms were also collected and identified from the samples at 870–900 feet in well No. 4.

The Grenola limestone can be traced southward out of Kansas into Oklahoma to well No. 22 in west-central Noble County. In this area the lower limestone beds disappear and the upper beds are believed to represent the Neva limestone zone of the outcrop in Pawnee County. The samples at 1,360–1,370 feet in well No. 22 contain fusulinids identified as Neva forms.

Admire group.—The Admire group ranges in thickness from 80 to 160 feet along the line of the cross sections. A thin, green to gray, glauconitic, dolomitic, fusulinid-bearing limestone occurs about 60 feet below the top of this group, which, on the basis of its fusulinids, has been identified by Waering[9] as the Falls City limestone. In well No. 22, fusulinid-bearing limestone in the samples from 1,660 to 1,670 feet is considered to represent the Falls City limestone. It has not been correlated in the cross sections because of the thinness of this bed and the uncertainty of recognizing it consistently on the electrical logs.

The Admire group represents the initial deposits of the Permian sediments in this area. In Kansas[10] the unconformity between the Permian and Pennsylvanian rocks is marked mainly by channel sand fillings (Indian Cave sandstone) which bring deposits classified as lowermost Wolfcampian into contact with rocks ranging downward from the Brownville limestone or possibly slightly younger to the Dover formation or lower. The Dover limestone occurs approximately 125 feet below the Brownville. On the surface in western Chautauqua County, Kansas, Moore[11] reports such local channel-filled deposits of the Indian Cave sandstone forming the base of the Admire group. The Indian Cave sandstone does not appear to be developed in any prominence in the cross sections, excepting possibly in well No. 28 where a sandstone from 580 to 600 feet may represent this zone. In the subsurface in the area investigated the boundary between the Admire group and the underlying Virgilian series of the Pennsylvanian is at best an inconspicuous disconformity.

[9] Erik K. Waering, personal communication.

[10] R. C. Moore, John C. Frye, and John Mark Jewett, "Tabular Desciption of Outcropping Rocks in Kansas," *Kansas Geol. Survey Bull. 52*, Pt. 4 (October, 1944), p. 170.

[11] R. C. Moore, *Guide Book Eleventh Annual Field Conference, Kansas Geol. Society* (1937), pp. 70, 83, 103.

PENNSYLVANIAN SYSTEM

The Pennsylvanian system consists of interbedded limestone, shales, and sandstones, whose combined thickness ranges from 1,580 feet at well No. 1, 2,985 feet at well No. 19, to 3,100 feet at well No. 28. These rocks are divided into the Virgilian, Missourian, and Desmoinesian series.

VIRGILIAN SERIES

The Virgilian series in the area studied in Kansas can be readily differentiated into the Wabaunsee, Shawnee, and Douglas groups. The Wabaunsee is the only one of the three groups which maintains a fairly uniform character and thickness where traced from Kansas into Oklahoma.

Where the lower and middle parts of this series of rocks are traced southward into Oklahoma, the limestone members of the Shawnee and Douglas groups disappear and there is an increase of shales and sandstones in zones equivalent to the Shawnee limestone beds of Kansas. Due to these facies changes the use of the Kansas classification for the lower and middle Virgilian series is generally not applicable in all the northern Oklahoma area which was studied.

Wabaunsee group.—The Wabaunsee group is characterized by the dominance of shale and relatively thin but persistent limestones that can be followed throughout the area. It is fairly uniform in thickness, ranging from 420 feet at well No. 2, 525 feet at well No. 19, to 485 feet at well No. 21. In the electrical-log cross sections the top of the Wabaunsee group is placed at the top of a thin, but rather persistent and characteristic "kick" on the lateral resistivity curve. This "kick" is believed to mark the position or zone of the Brownville limestone. The continuity of this zone is not well established. The writer examined cuttings of some of the wells and found a thin limestone at this horizon. In other wells examined no limestone was present. It is possible that the limestone was too thin to be detected in the samples. It is also possible that the limestone was removed by post-Pennsylvanian erosion in a manner similar to that reported by field geologists at several places where the top of the Pennsylvanian is exposed.

There has been some question concerning the upper limit of the Wabaunsee group on the surface in northern Osage County. This is due to confusion about the surface mapping of two closely associated beds, namely, the Brownville and Grayhorse limestones. However, as a result of field studies, Moore[12] concluded that ". . . in most places the limestone mapped as Grayhorse in Oklahoma is really Brownville." In the cross sections the Brownville limestone is correlated with the Grayhorse limestone of the surface section at well No. 33.

Other limestones identified in the Wabaunsee group are the Elmont-Reading, Wakarusa, Burlingame, Happy Hollow, and Howard. All of these with the exception of the Happy Hollow and the Burlingame limestones have been traced

[12] R. C. Moore, "Annotated Index of Stratigraphic Terms Applied to Pennsylvanian and Lower Permian Rocks in Southern Kansas and Northern Oklahoma," *ibid.*, p. 100.

throughout the cross sections. Fusulinids in limestone in the samples from 2,070 to 2,080 feet in well No. 21 and from 2,190 to 2,000 feet in well No. 22 have been identified as Howard forms. On the surface, according to Moore[13] the Elmont-Reading, Wakarusa, and Howard limestones of Kansas are considered to be the equivalent of the Stonebreaker, "Cryptozoan," and Bird Creek limestones of Oklahoma, respectively, and these correlations are used in the cross sections.

Shawnee group.—The Shawnee group in Kansas is composed of the Topeka limestone, Calhoun shale, Deer Creek limestone, Tecumseh shale, Lecompton limestone, Kanwaka shale, and Oread limestone; however, not all are differentiated in the cross sections. Between wells 1 and 15 the group consists primarily of limestones and shales which can best be regarded as a unit. Farther south in Oklahoma several limestones are replaced by shales and sandstones. None of the members of the Shawnee group can be traced the length of the cross sections because the limestones disappear, or are discontinuous, or become so thin that they can not be followed to the outcrop in southern Osage County. Excepting this fact, such limestones as the Topeka, Deer Creek, and Oread are very useful markers in subsurface correlation because they are well developed beds in Noble and Garfield counties, Oklahoma. Fusulinids in the samples from 2,230 to 2,240 feet in well No. 21 and from 2,350 to 2,360 feet in well No. 22 are identified as Deer Creek forms. Even though it has not been possible to trace the limestones in the Shawnee group to the outcrop in eastern Pawnee and southern Osage counties, Oklahoma, the surface correlation of the members of the Pawhuska formation with members in the Topeka, Deer Creek, and Lecompton limestones has been well established in earlier studies by other geologists.

The Elgin sandstone of southern Osage County (geologic section at well No. 33) can be traced underground to well No. 19 in Garfield County. It constitutes the only stratigraphic unit in the middle Virgilian series which can be traced continuously along the line of cross section *BC*. In this cross section the Elgin sandstone is correlated with the sandstones which occur in a shale on the Oread limestone. This shale is considered to be the Kanwaka formation. This conclusion agrees with that of Murray[14] who has traced the Elgin sandstone on the surface from southern Osage County northward into Kansas. The writer considers the Elgin sandstone of the surface to be wholly or partly correlative with the lowermost sandstone of the Hoover zone as used by petroleum geologists.

Several members of the Oread limestone, for example, the Plattsmouth limestone, Heebner shale, Leavenworth limestone, Snyderville shale, and Toronto limestone, have been identified and traced from well No. 1 in Marion County, Kansas, to well No. 22 in west-central Noble County, Oklahoma. These beds are useful subsurface markers. The writer's cross-sectional studies show clearly the marked similarity in sequence, in thickness, and in interval changes of the mem-

[13] R. C. Moore, *ibid.*, pp. 102, 104, 106.

[14] A. N. Murray, *Guide Book Oklahoma City Geol. Society* (November, 1946), Pl. IX.

bers of the Oread limestone in the subsurface and equivalent rocks on the outcrop in Kansas.[15]

The Plattsmouth limestone member varies from 15 to 80 feet in thickness. This member in the subsurface is generally referred to as the "Oread" limestone by Oklahoma geologists. It rests on the Heebner shale which is less than 10 feet in thickness in the wells where it has been identified. Well cuttings indicate that the Heebner contains a black shale bed which radioactivity logging shows to be highly radioactive. The highly radioactive Heebner shale and two similar shales in the Shawnee group can be noted in Figure 3 where the radioactivity and electrical-log surveys of well No. 4 are illustrated.

Underlying the Heebner shale is the Leavenworth limestone, a very thin but persistent bed, which generally can be recognized on the electrical logs. The next underlying shale is the Snyderville shale which is very thin in the two wells in Marion County, Kansas, but thickens gradually toward the south to nearly 200 feet in well No. 16.

The Snyderville shale contains beds of sandstone thought to be equivalent to the Wynona sandstone zone of the outcrop in southern Osage County.

The Toronto limestone which marks the base of the Shawnee group in Kansas occurs below the Snyderville shale. It is 10–20 feet thick. The Toronto limestone is recognized from well No. 1 to well No. 22; its absence farther east is believed due to non-deposition.

On the basis of other correlation studies by the writer, the Deer Creek limestone is thought to be correlative with the so-called "Pawhuska" limestone in the Tonkawa pool.[16] Similarly the sands between the Deer Creek and Plattsmouth limestones are thought to comprise the Hoover sand zone at Tonkawa, and the sandstone which occurs in the Snyderville shale section is correlated with the Endicott zone. The "Lovell"[17] limestone, a term used by some workers, is considered the equivalent of the Toronto limestone.

Douglas group.—The Douglas group comprises those rocks from the base of the Toronto limestone to the base of the Virgilian series. Its thickness varies from 220 feet in Marion County, Kansas, to 400 feet in well No. 15 in northeastern Grant County, Oklahoma. The Douglas group consists predominantly of varicolored shales with a few thin limestones and with prominent sandstones in the lower part. The top of the group can be traced southward from Marion County to

[15] R. C. Moore, *op. cit.*, p. 68, Fig. 23.

[16] G. C. Clark and F. L. Aurin, "The Tonkawa Field, Oklahoma," *Bull. Amer. Assoc. Petrol Geol.*, Vol. 8, No. 3 (May–June, 1924), pp. 269–83.
J. F. Hosterman, "The Tonkawa Oil and Gas Field," *ibid.*, pp. 284–300.

[17] W. Baxter Boyd, personal communication.
According to Boyd the term "Lovell" was applied to a limestone approximately 175 feet below the "Oread" limestone and was first noted by M. D. Scruggs in the Welch-Acton and Brown's Lovell No. 1, SW. ¼, SW. ¼, NW. ¼, Sec. 9, T. 18 N., R. 4 W., Logan County, Oklahoma. From the driller's log the writer interprets the limestone reported from 3,795 to 3,805 feet as "Lovell."

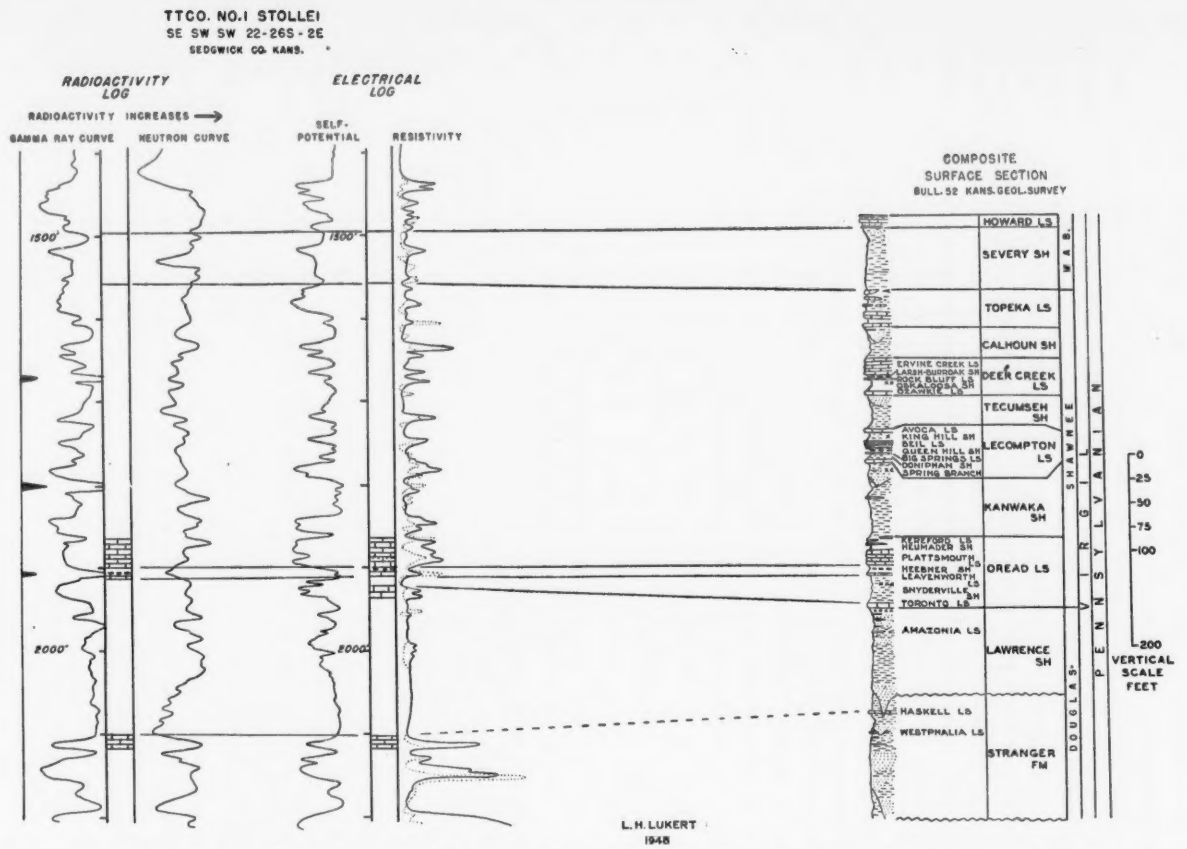


FIG. 3.—Comparison of radioactivity log and electrical log from The Texas Company's Stollei No. 1 (well No. 4, cross section *AB*, Pl. I) with composite surface section. Heebner shale and other lithologically similar shales are indicated as highly radioactive on radioactive survey.

well No. 22 in western Noble County east of which it is obscure. Southward from well No. 5 one or more beds of sandstones occur at the base of the Douglas group and these offer some evidence of a disconformity separating the Virgilian and Missourian rocks. The disconformity is not conspicuous in this area but it is thought to be the equivalent of the greater physical break found farther south near the Arbuckle Mountain region where Missourian rocks were removed by erosion and overlapped progressively by the Vamoosa, Ada, and Vanoss formations.[18]

In the area between wells 3 and 19 a thin persistent limestone occurs approximately 30 feet below the top of the Douglas group. This limestone occupies the position of the Amazonia limestone on the surface and it has been questionably correlated with it.

The shale section below the Amazonia (?) limestone contains sandy beds which have been correlated with the Ireland sandstone. The best development of this sandstone is in wells 1 and 2 in Marion County, Kansas, and well No. 17 in southeastern Grant County, Oklahoma. This section, together with the Amazonia limestone, is considered to be correlative with the Lawrence shale of the Kansas surface section.

Surface beds in Kansas from the base of the Ireland sandstone to the base of the Tonganoxie sandstone are classified as the Stranger formation. The Stranger formation contains the Haskell and Westphalia limestones and the Tonganoxie sandstone.

A fusulinid-bearing limestone at 1,890–1,900 feet in well No. 5A (Fig. 4) has been identified as the Haskell limestone. It is a thin but fairly persistent, impure, sandy limestone which can be traced as far south as well No. 19.

In wells 3, 4, and 5, oölitic limestone occurs approximately 25 feet below the Haskell and by its position in the section has been questionably correlated with the Westphalia limestone of Kansas. Surface sections in Kansas indicate that the Tonganoxie sandstone, which marks the base of the Virgilian series, occurs below the Westphalia limestone. Unfortunately the writer's sections do not permit a definite correlation with an established subsurface or surface section which contains the Tonganoxie sandstone. However, if the writer's identification of the Westphalia limestone is correct, any sandstone below this limestone probably represents the Tonganoxie.

Figure 4, which shows a cross section involving wells 3–7, illustrates the lithologic changes of some of the beds encountered in the lower Virgilian and upper Missourian series. The lithologic description in this cross section is based on sample and electrical-log data. The small included index map shows that well No. 5A, in the SE. ¼, SE. ¼, SW. ¼, Sec. 26, T. 27 S., R. 3 E., Butler County, Kansas, has been added to show the position of a zone of sandy beds below the Westphalia(?) limestone. These sandy beds are believed to be the Tonganoxie.

[18] Malcolm C. Oakes, *Guide Book Oklahoma City Geol. Society*, Pt. III (1946), p. 10.

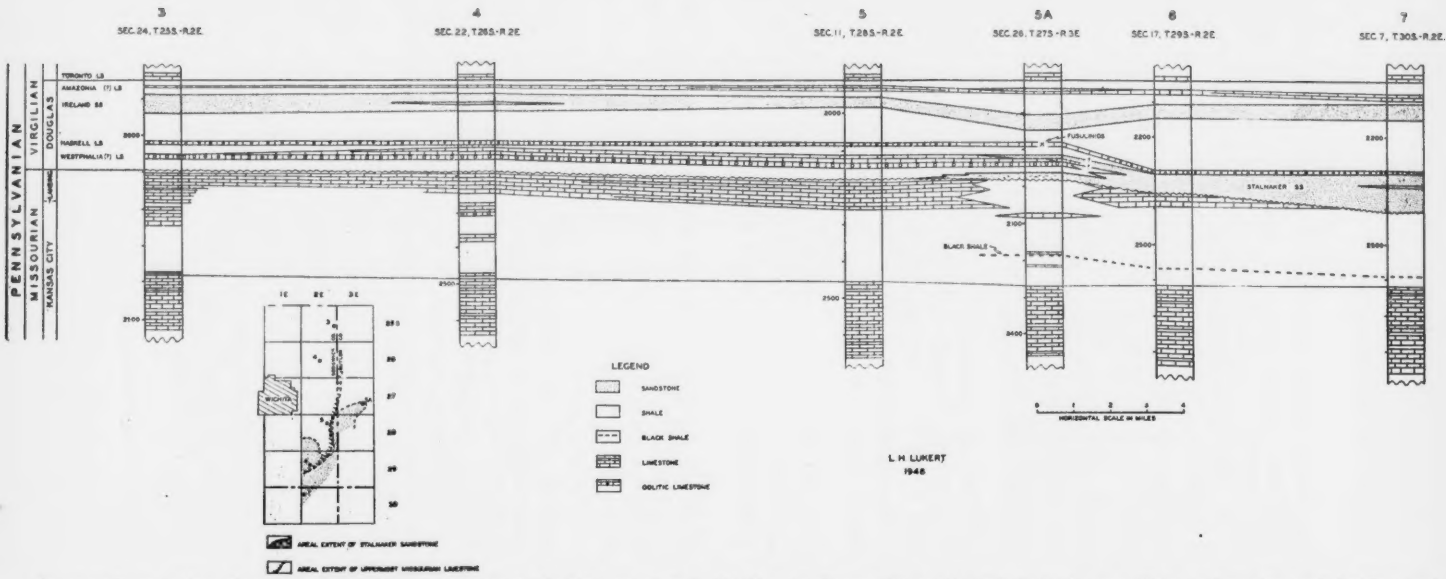
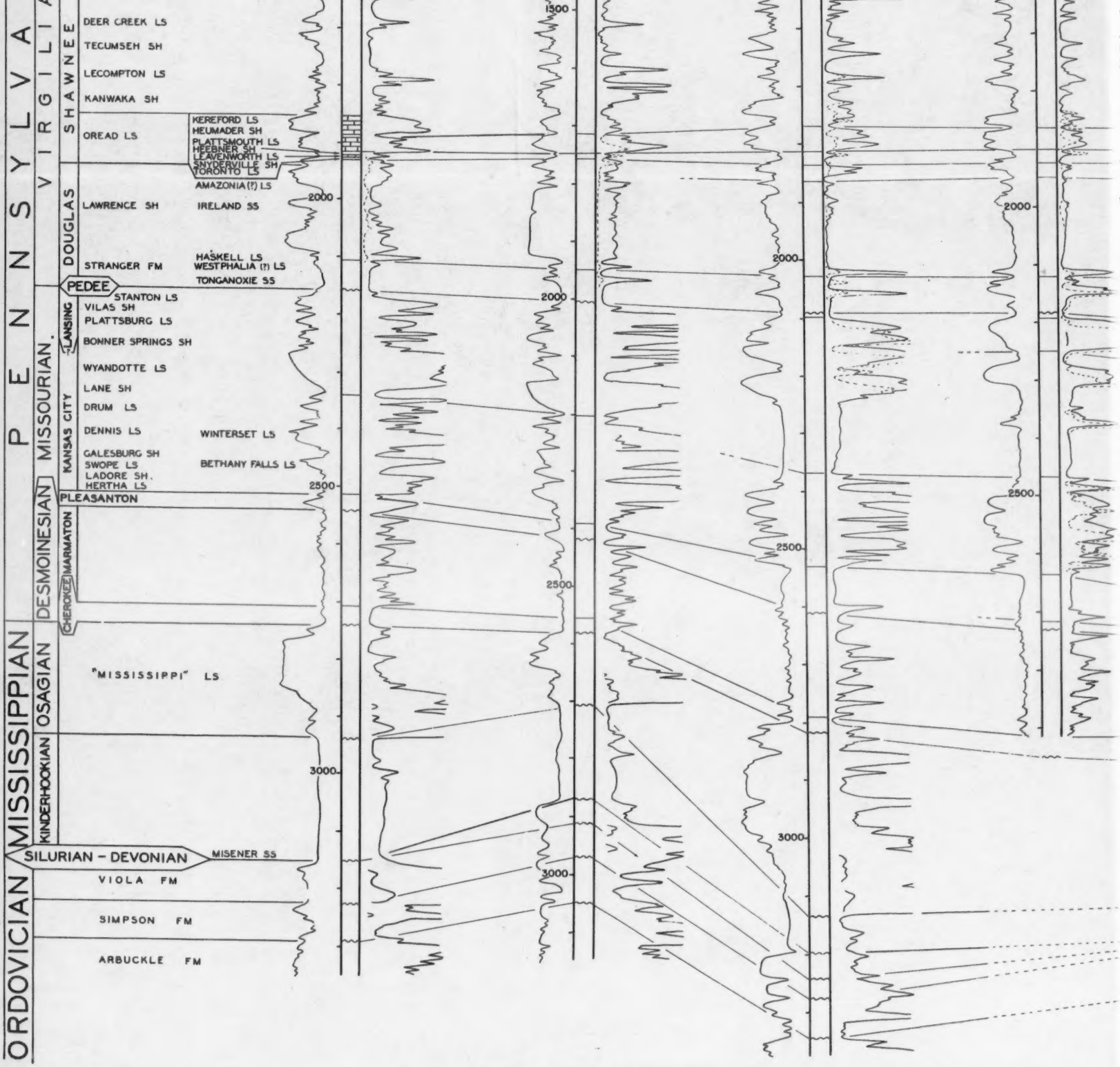
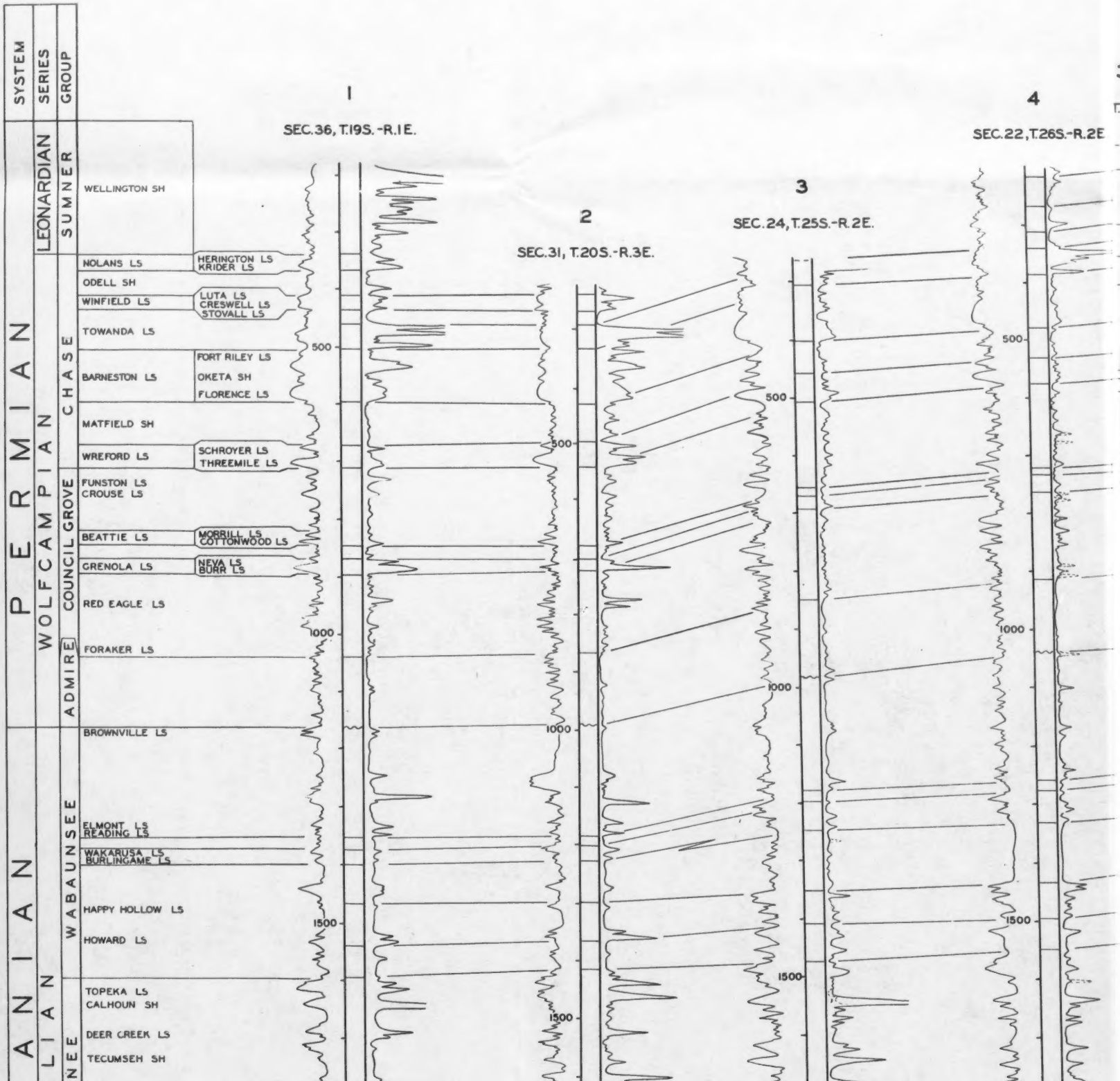


FIG. 4.—Cross section of lower Virgilian and upper Missourian beds in eastern Sedgwick County Kansas, illustrating lithologic changes. Well numbers refer to Table I excepting No. 5A, The Texas Company's Hutchins No. 1, SE. ¼, SE. ¼, SW. ¼, Sec. 26, T. 27 S., R. 3 E., western Butler County, which is included to show relationship of Stalnaker sandstone to lower Virgilian limestones and shales.



PL. I.—Subsurface geologic cross section *AB* from Marion County, Kansas, to Garfield County, Oklahoma. For location of cross section and wells see Figure 2. Horizontal distances not
Datum, base of Plattsmouth limestone member of Oread limestone. Beds marked with asterisk (*) are terms used in Tonkawa pool reports.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LEONARDIAN
SUMNER
WOLFCAMPIAN
CHASE
COUNCIL GROVE
ADMIRE
WABAUNSEE
SHAWNEE
WELLINGTON SH
NOLANS LS
HERINGTON LS
KRIDER LS
ODELL SH
WINFIELD LS
LUTA LS
CRESWELL LS
STOVALL LS
TOWANDA LS
FORT RILEY LS
BARNESTON LS
OKETA SH
FLORENCE LS
MATFIELD SH
WREFORD LS
SCHROYER LS
THREEMILE LS
FUNSTON LS
CROUSE LS
BEATTIE LS
MORRILL LS
COTTONWOOD LS
GRENOLA LS
NEVA LS
BURR LS
RED EAGLE LS
FORAKER LS
BROWNVILLE LS
ELMONT LS
READING LS
WAKARUSA LS
BURLINGAME LS
HAPPY HOLLOW LS
HOWARD LS
TOPEKA LS
CALHOUN SH
DEER CREEK LS
TECUMSEH SH
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SEC.36, T.19S.-R.1E.
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SEC.31, T.20S.-R.3E.
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SEC.24, T.25S.-R.2E.
4
SEC.22, T.26S.-R.2E
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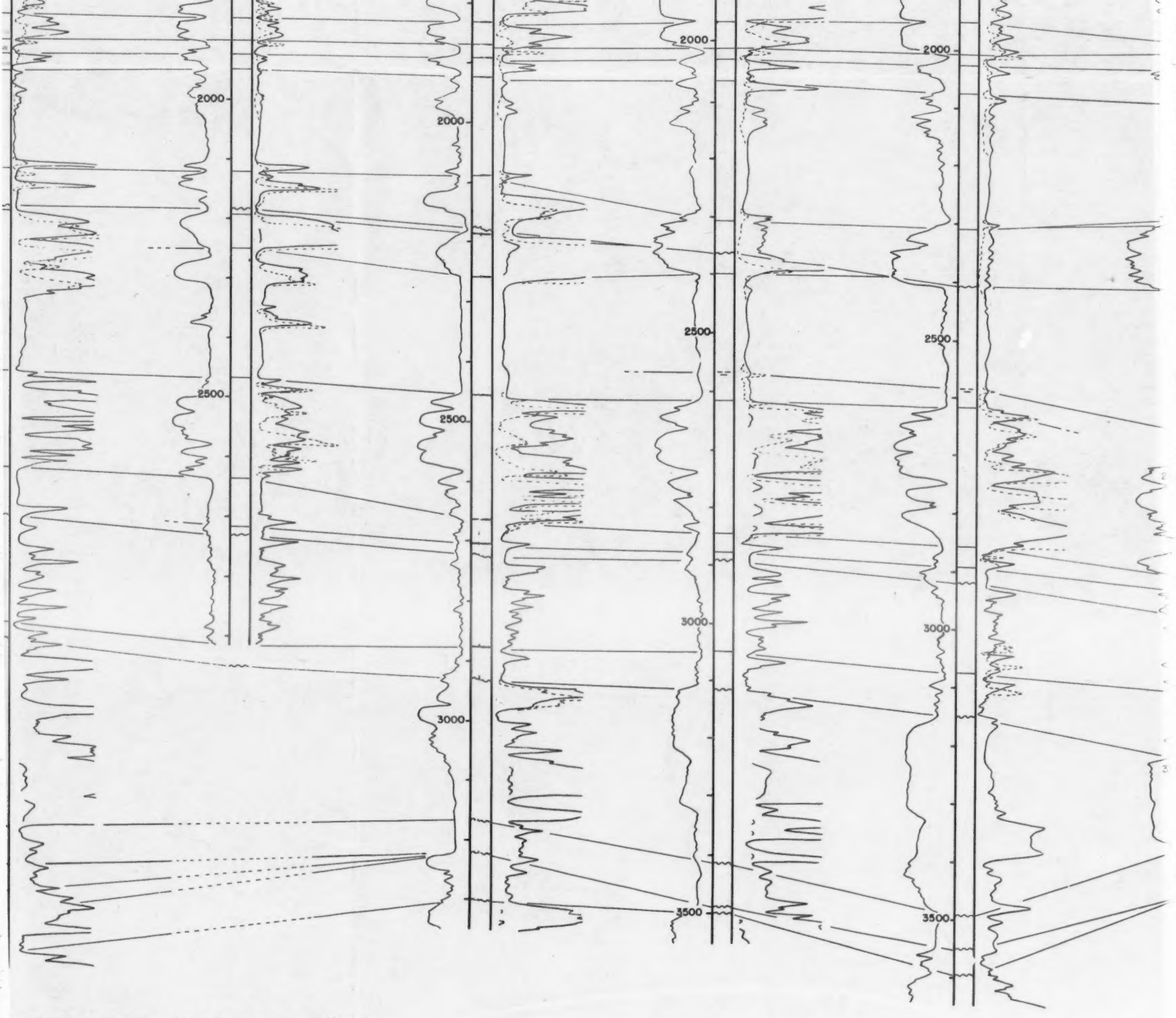
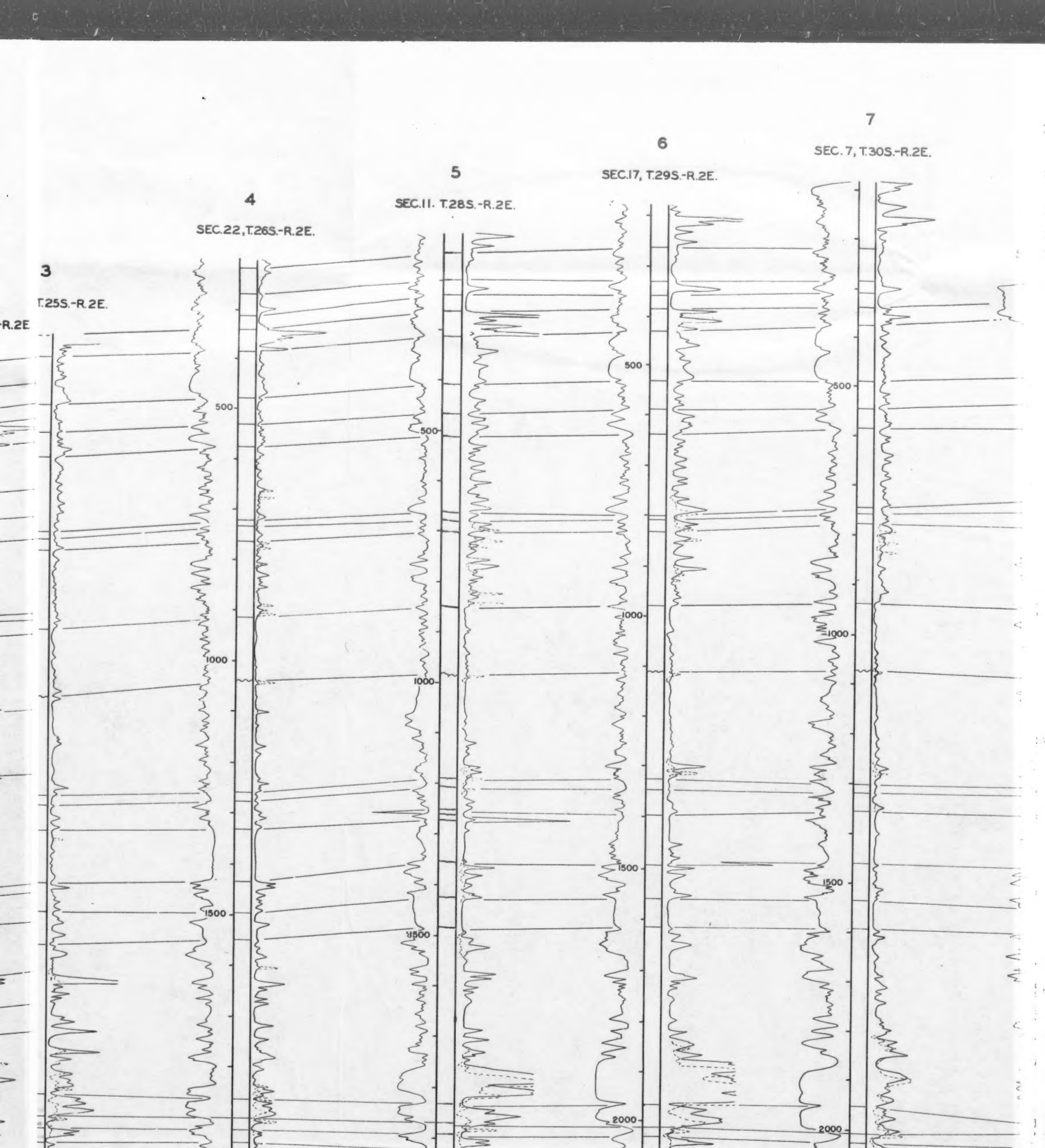


n and wells see Figure 2. Horizontal distances not to scale.
is used in Tonkawa pool reports.


3
T.25S.-R.2E.
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SEC.22, T.26S.-R.2E.
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SEC.11. T.28S.-R.2E.
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SEC.17, T.29S.-R.2E.
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SEC. 7, T.30S.-R.2E.
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PLATTSMOUTH LS
TORONTO LS
AMAZONIA (?) LS
HASKELL LS
STALNAKER SS
"LAYTON" SS
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SIMPSON
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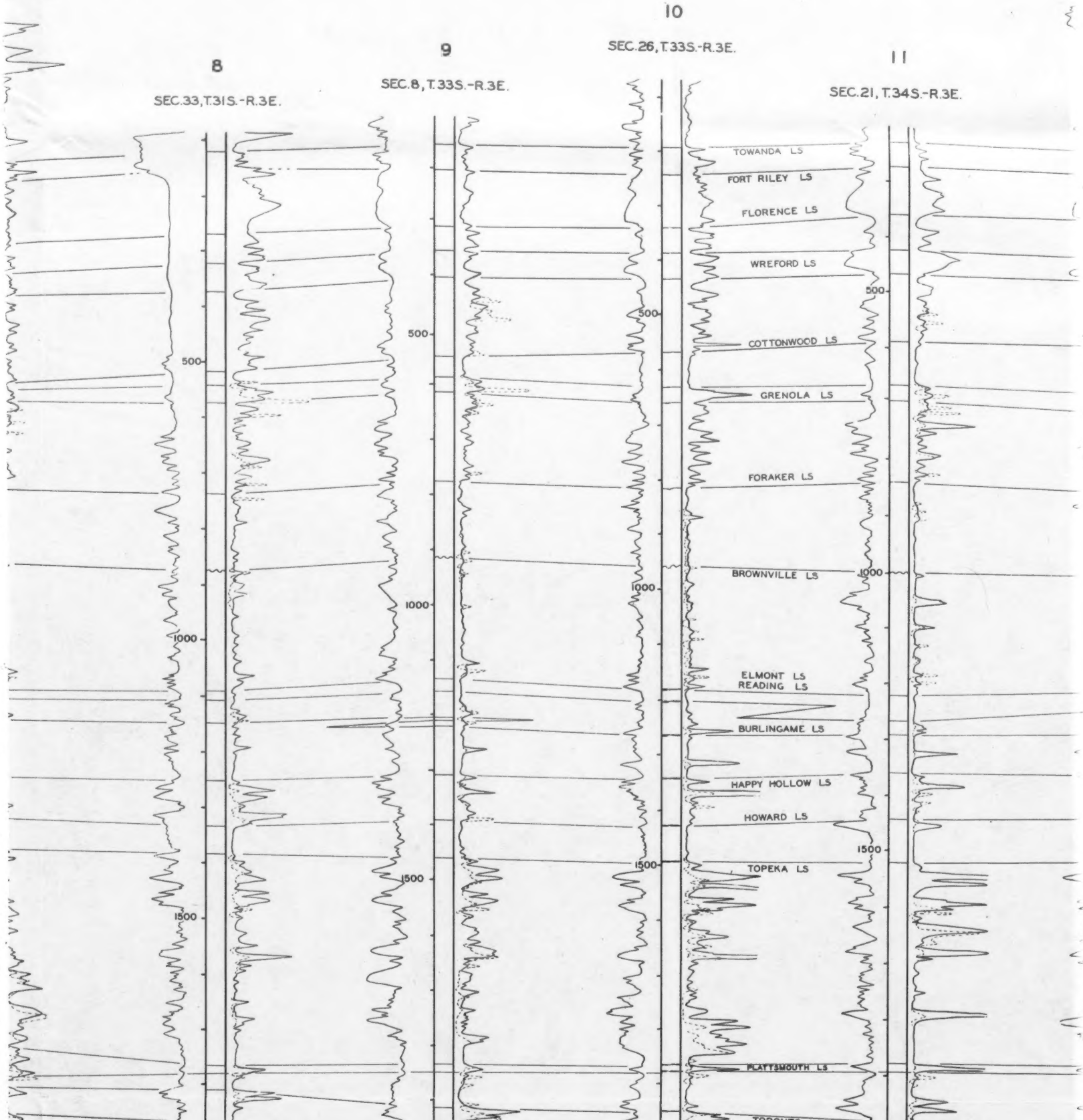
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FLORENCE LS
WREFORD LS
COTTONWOOD LS
GRENOLA LS
FORAKER LS
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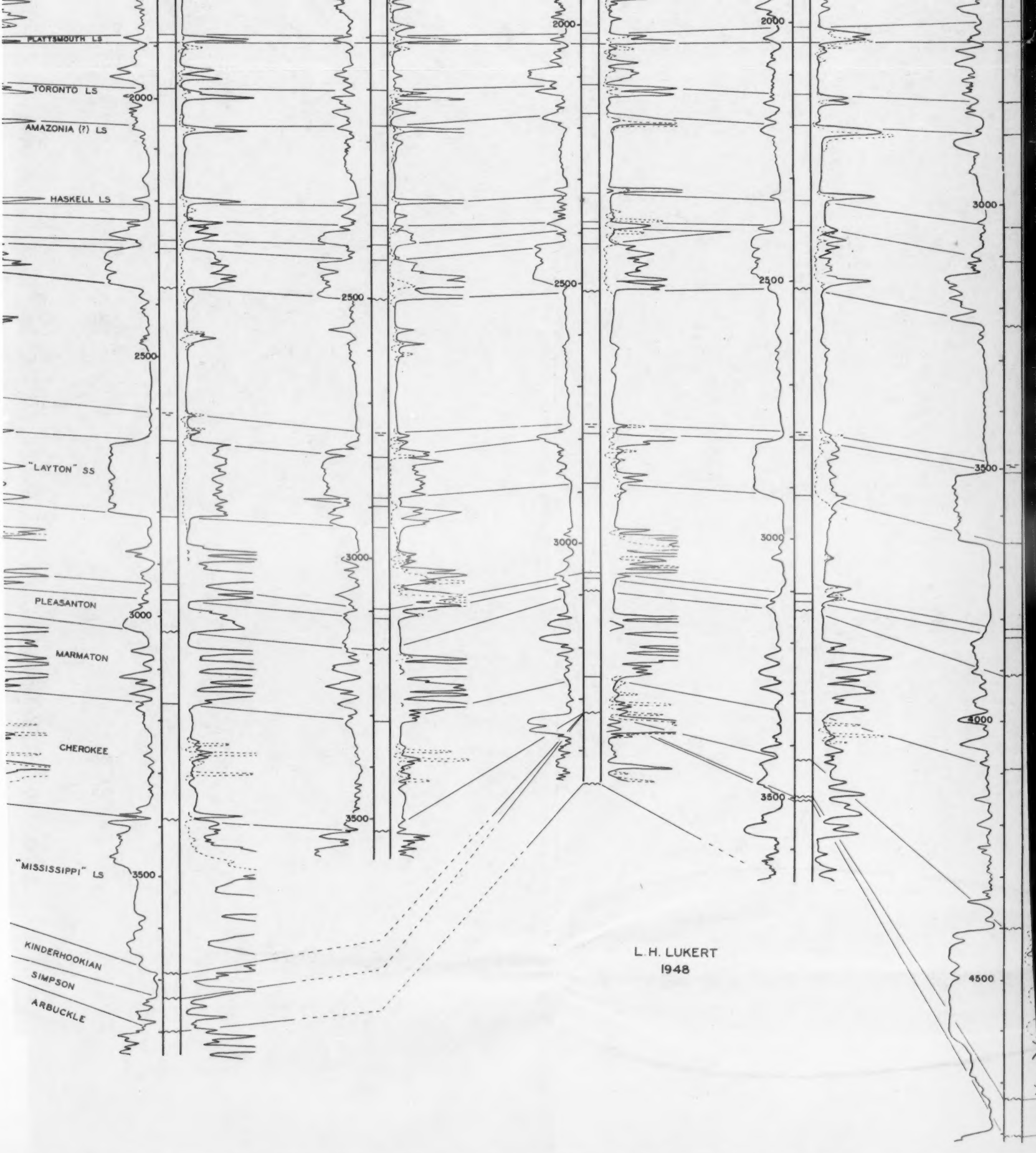
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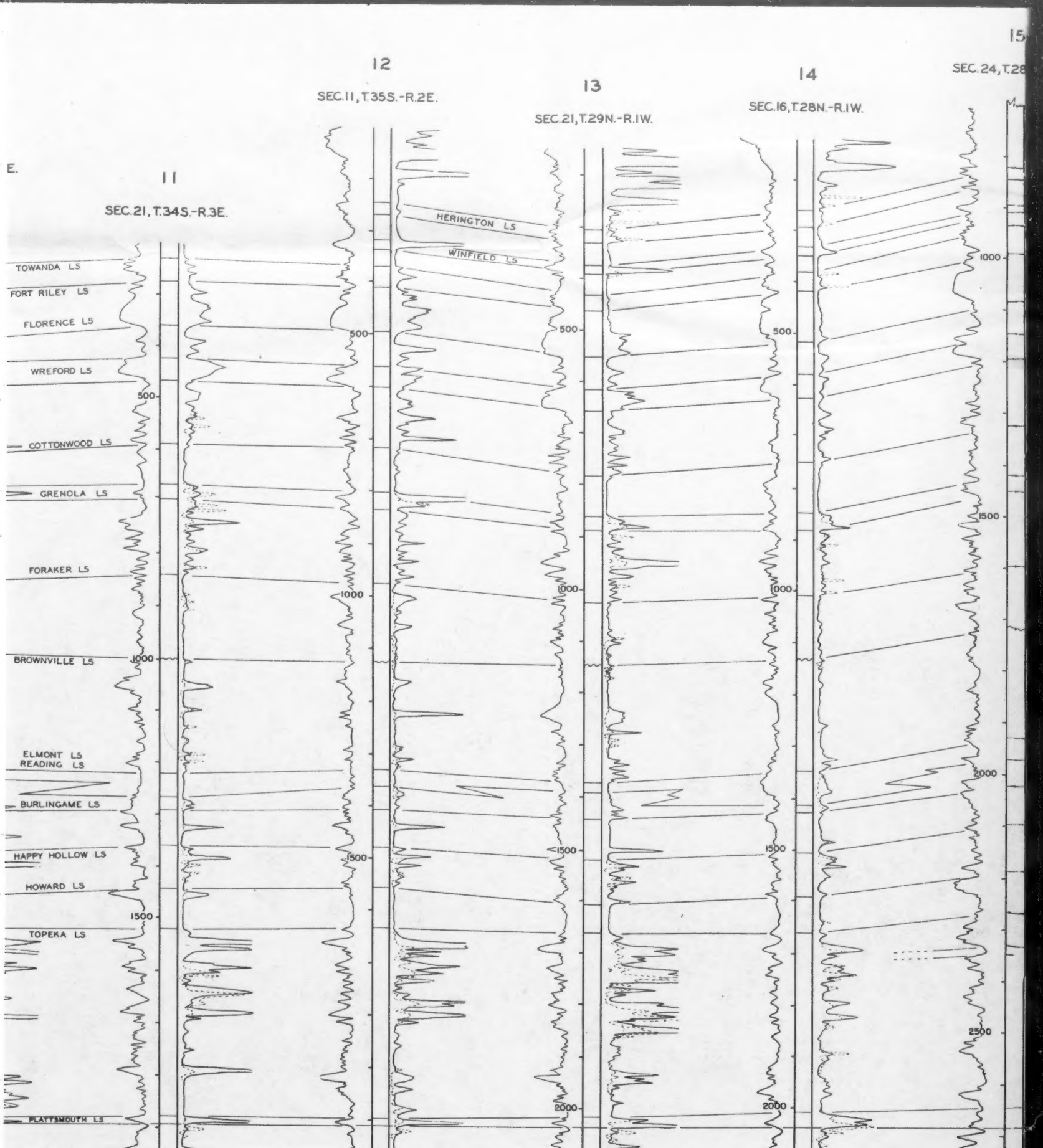
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13
SEC.21, T.29N.-R.1W.
14
SEC.16, T.28N.-R.1W.
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SEC.24, T.28
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FORAKER LS
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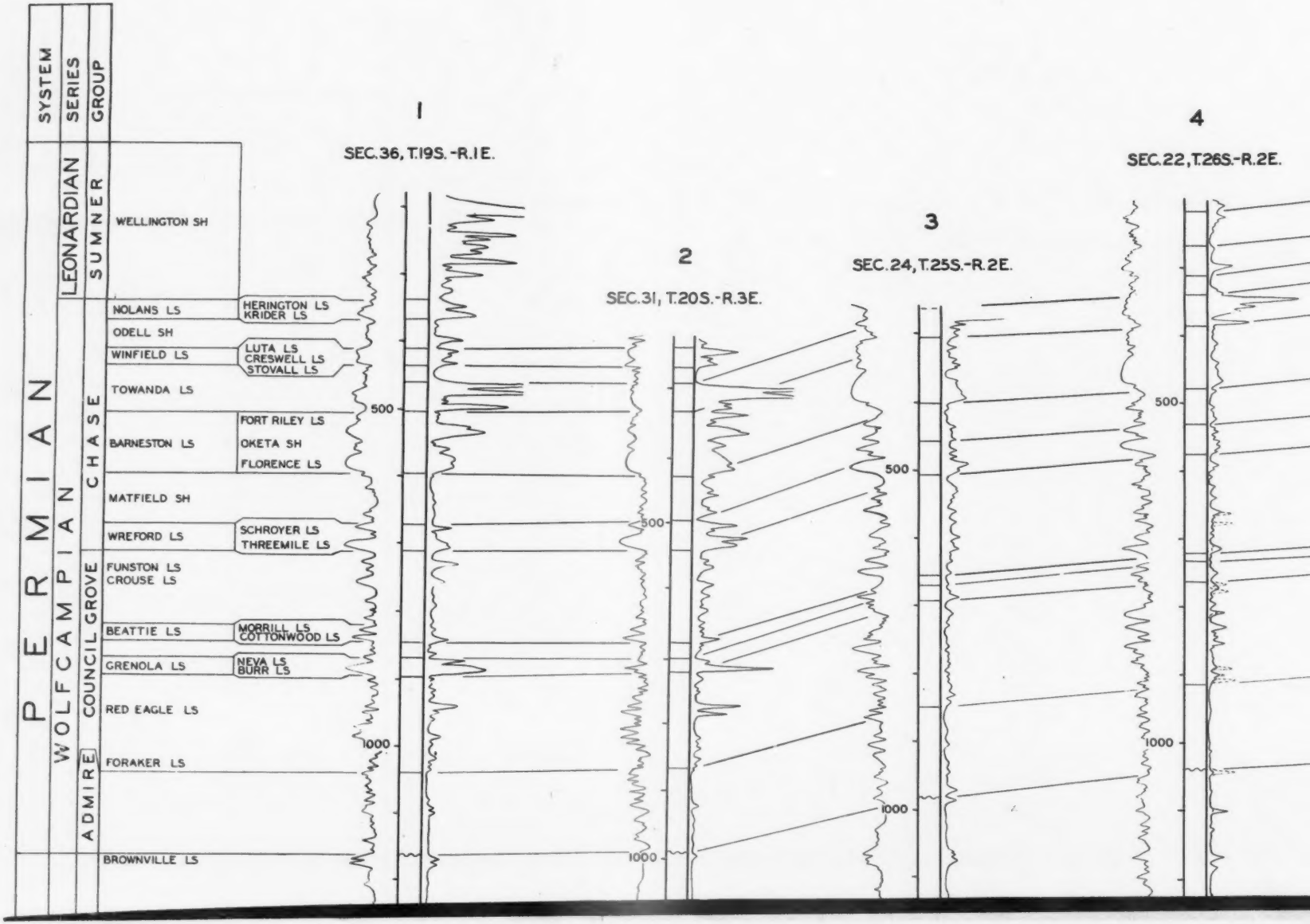
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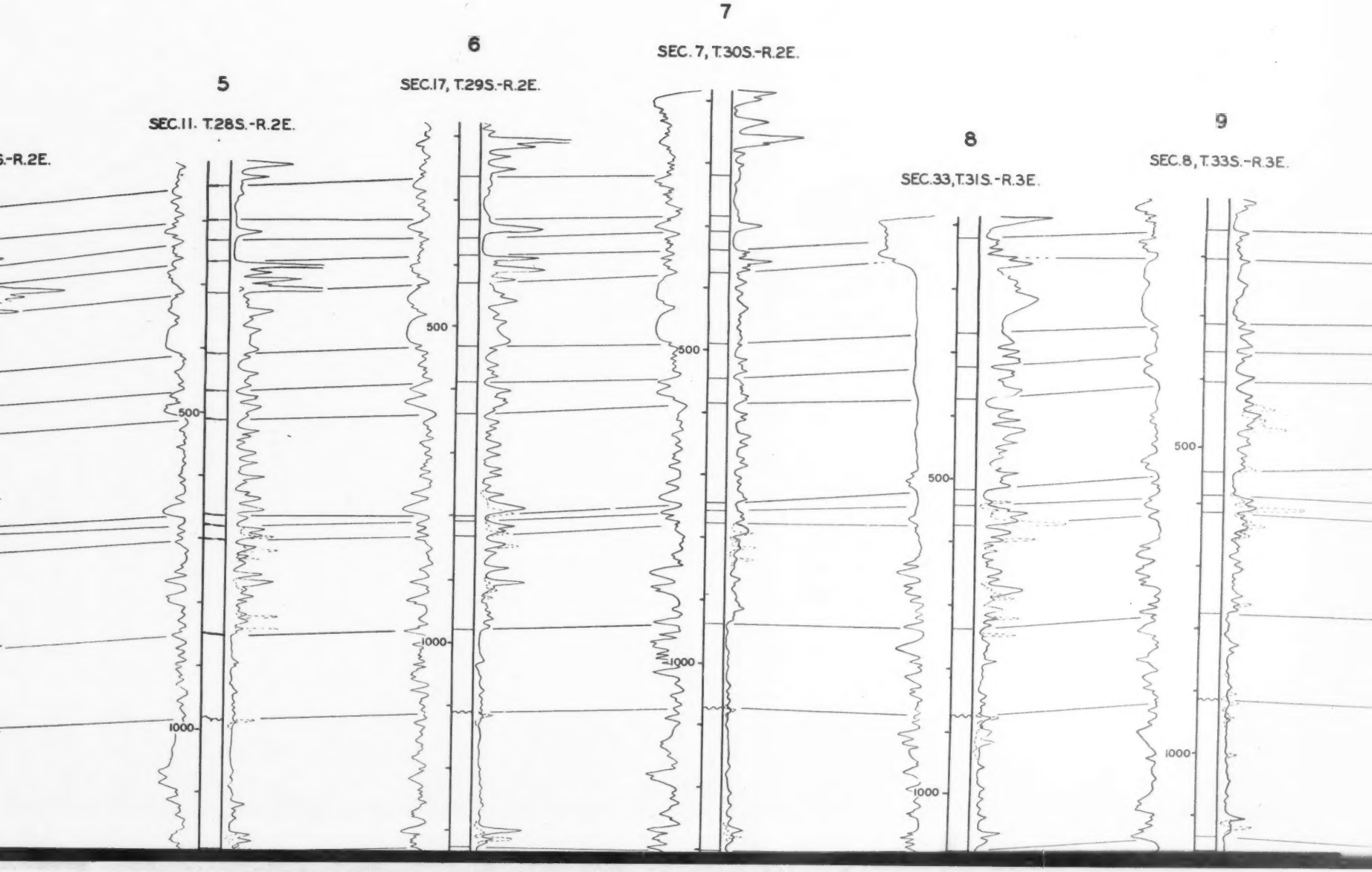
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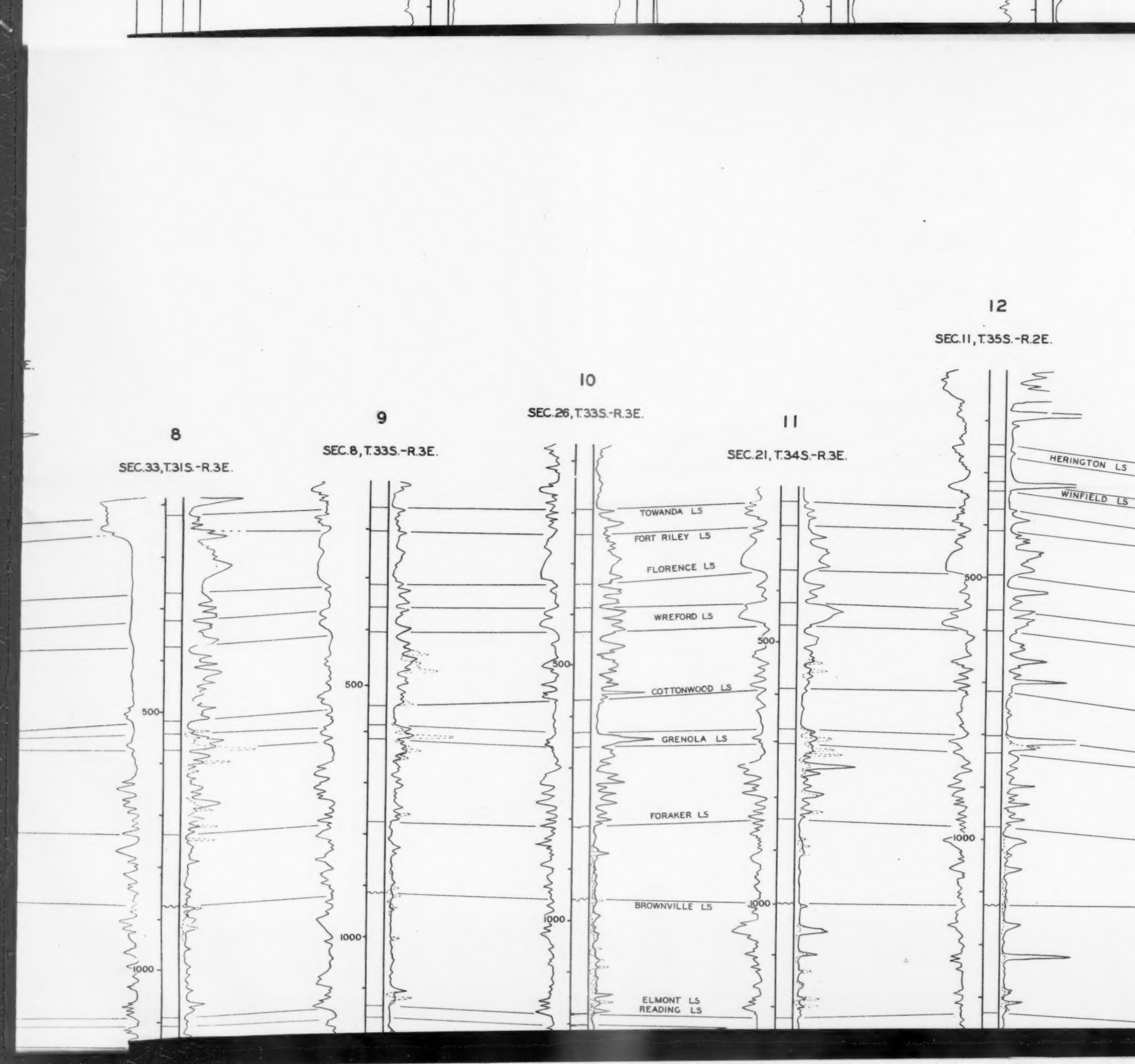
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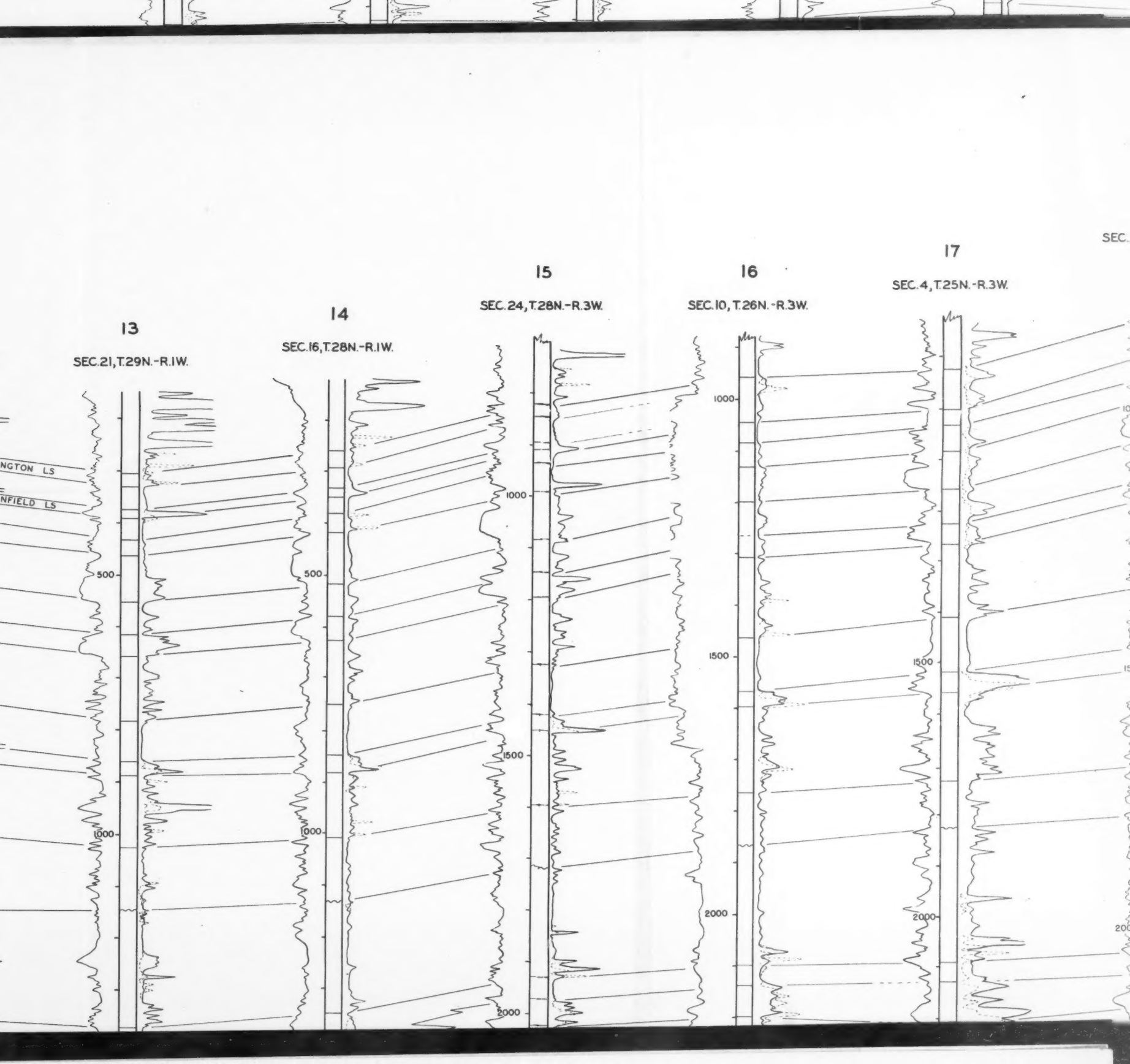
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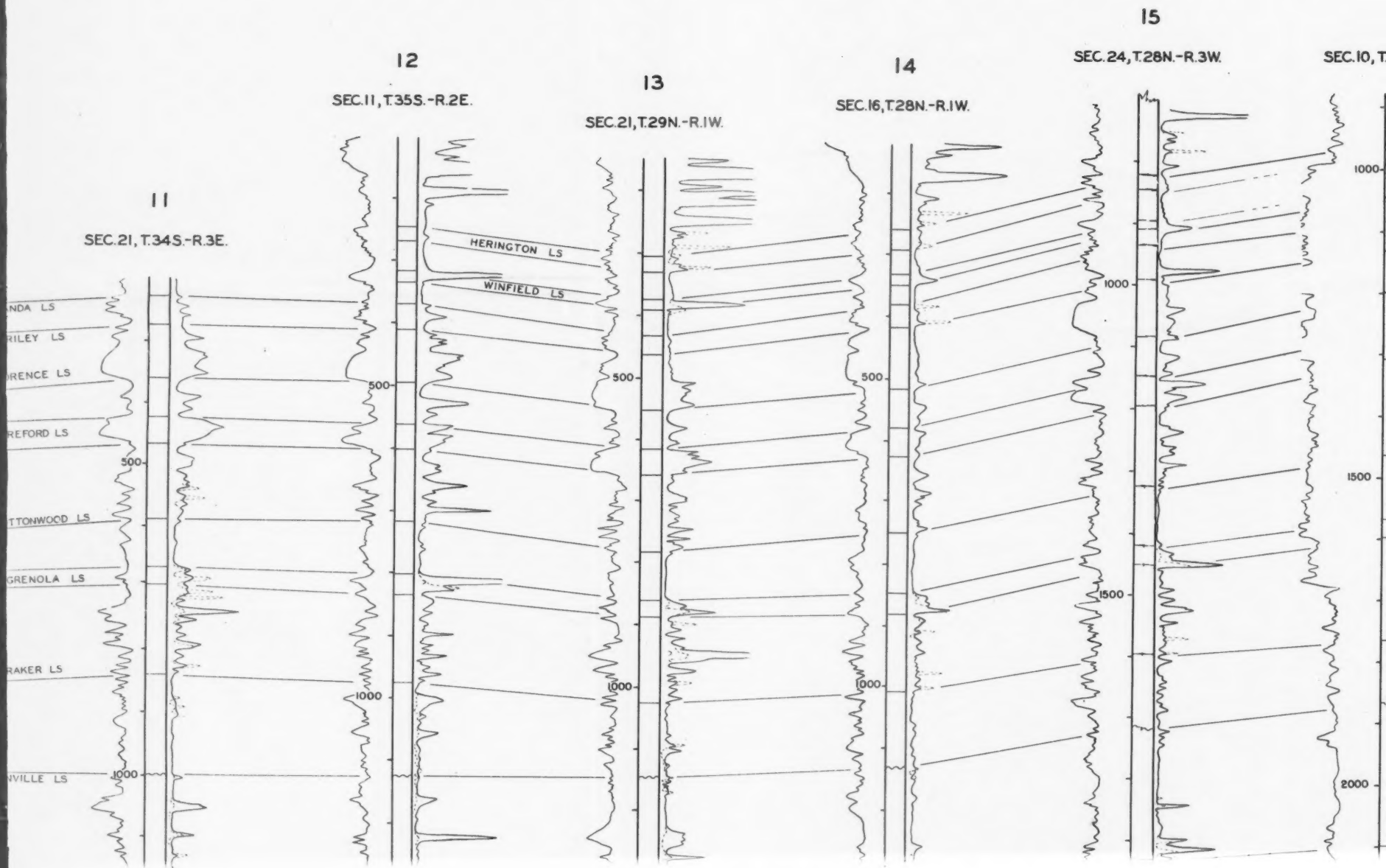
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SEC. 24, T. 28 N.-R. 3 W.
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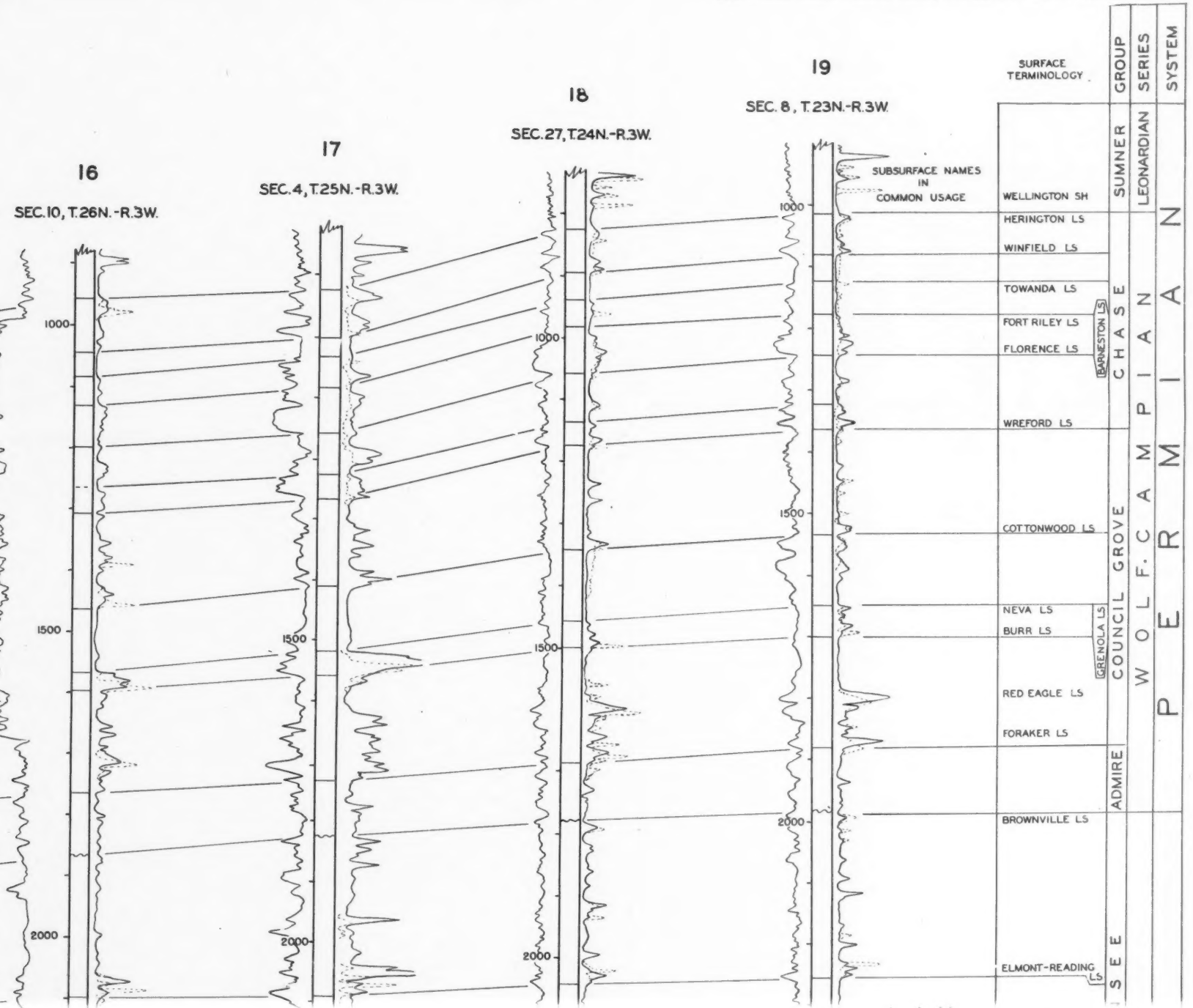
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SEC. 8, T. 23N. - R. 3W.
SUBSURFACE NAMES IN COMMON USAGE
SURFACE TERMINOLOGY
SYSTEM
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GROUP
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WOLFCAMPIAN
LEONARDIAN
SUMNER
CHASE
COUNCIL GROVE
ADMIRE
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FLORENCE LS
BARNESTON LS
WREFORD LS
COTTONWOOD LS
NEVA LS
BURR LS
GRENOLA LS
RED EAGLE LS
FORAKER LS
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PENNSYLVANIAN
SIPPIAN
OSAGIAN
DESMOINESIAN
MISSOURIAN
VIRGILIAN
ADM
WABAUNSEE
SHAWNEE
DOUGLAS
LANSING
KANSAS CITY
CHEROKEE
MARMATON
PEDEE
PLEASANTON
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ELMONT LS
READING LS
WAKARUSA LS
BURLINGAME LS
HAPPY HOLLOW LS
HOWARD LS
TOPEKA LS
CALHOUN SH
DEER CREEK LS
TECUMSEH SH
LECOMPTON LS
KANWAKA SH
OREAD LS
KEREFORD LS
HEUMADER SH
PLATTSMOUTH LS
HEEBNER SH
LEAVENWORTH LS
SNYDERVILLE SH
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LAWRENCE SH
IRELAND SS
STRANGER FM
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TONGANOXIE SS
STANTON LS
VILAS SH
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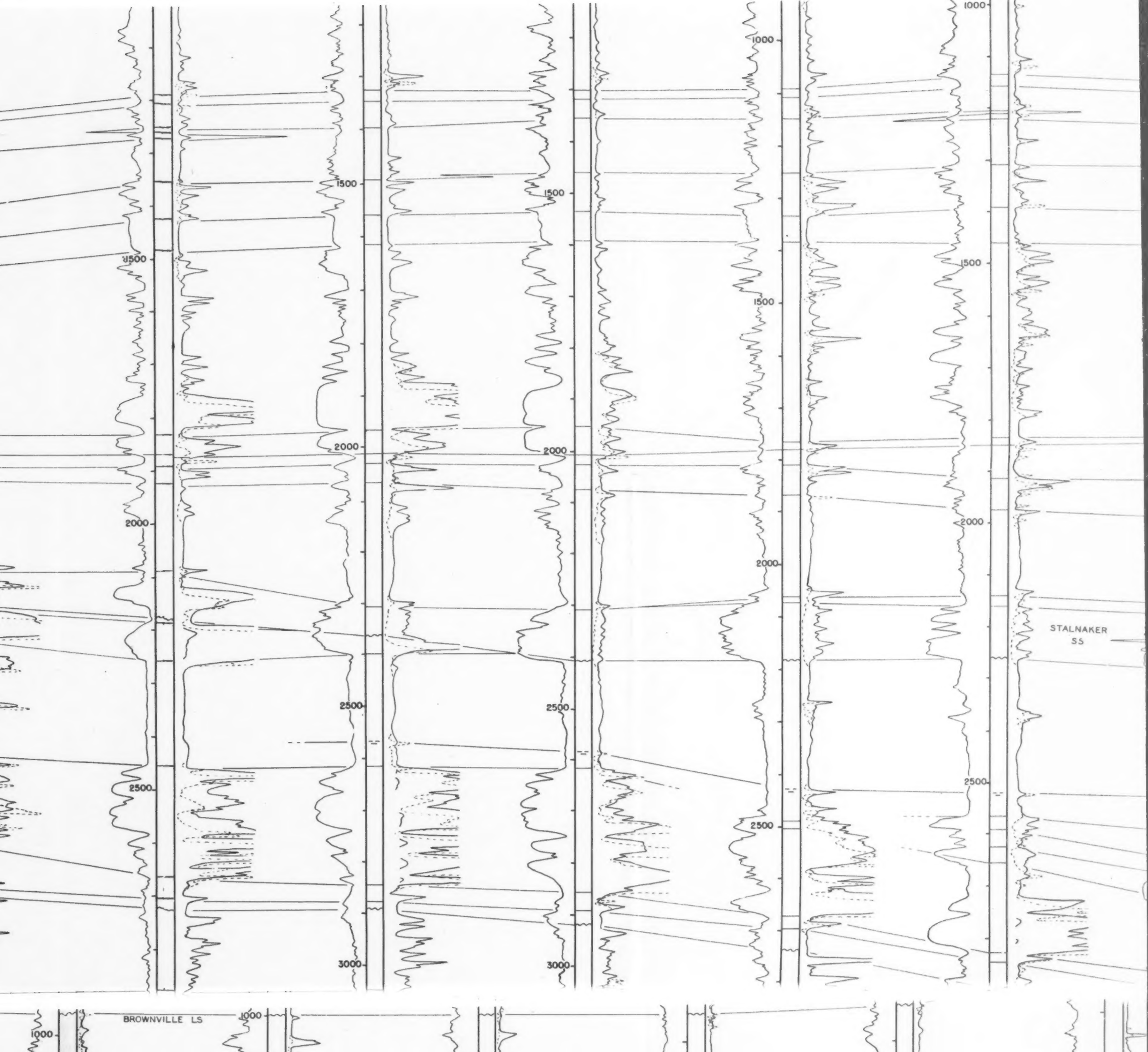
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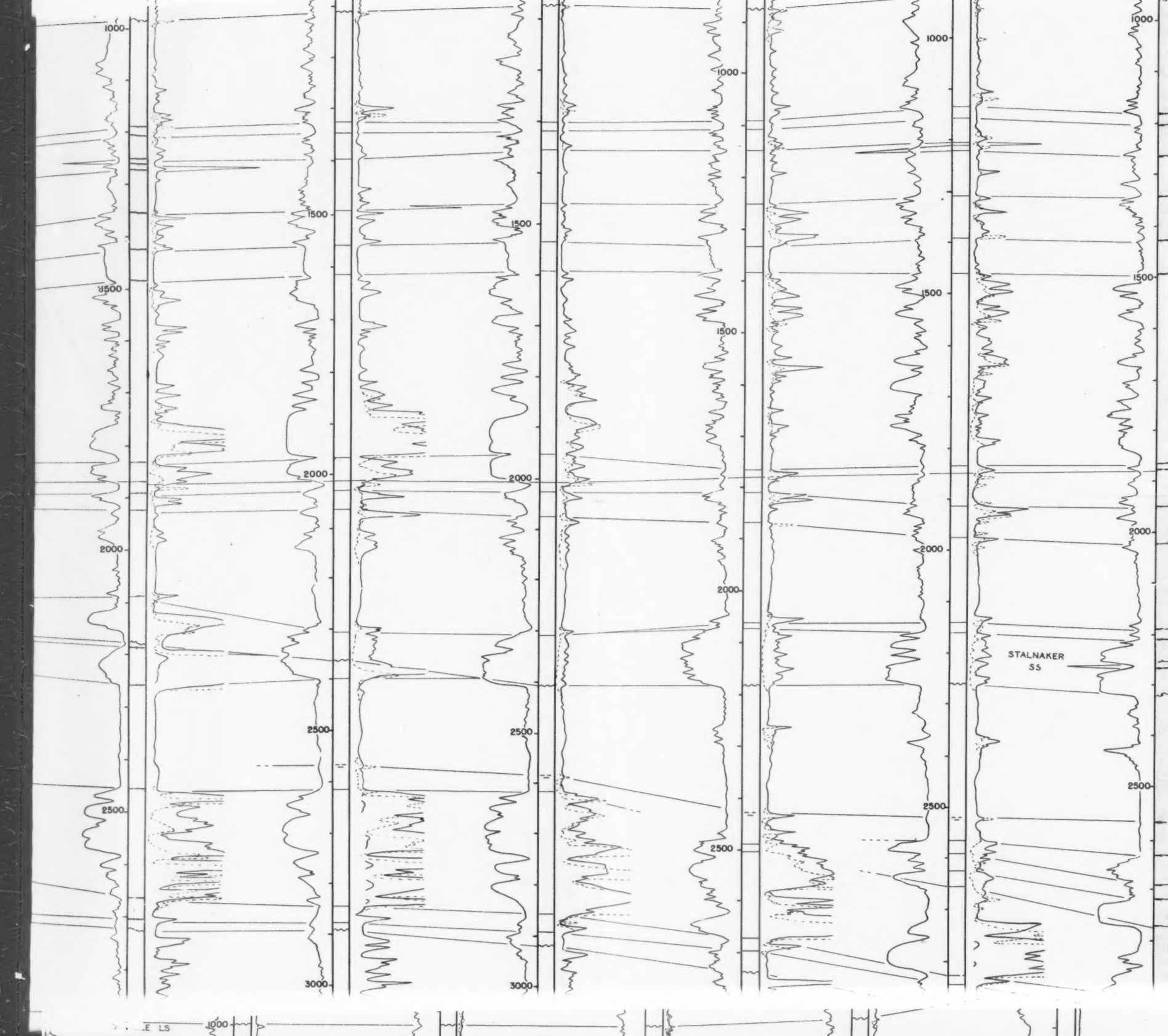
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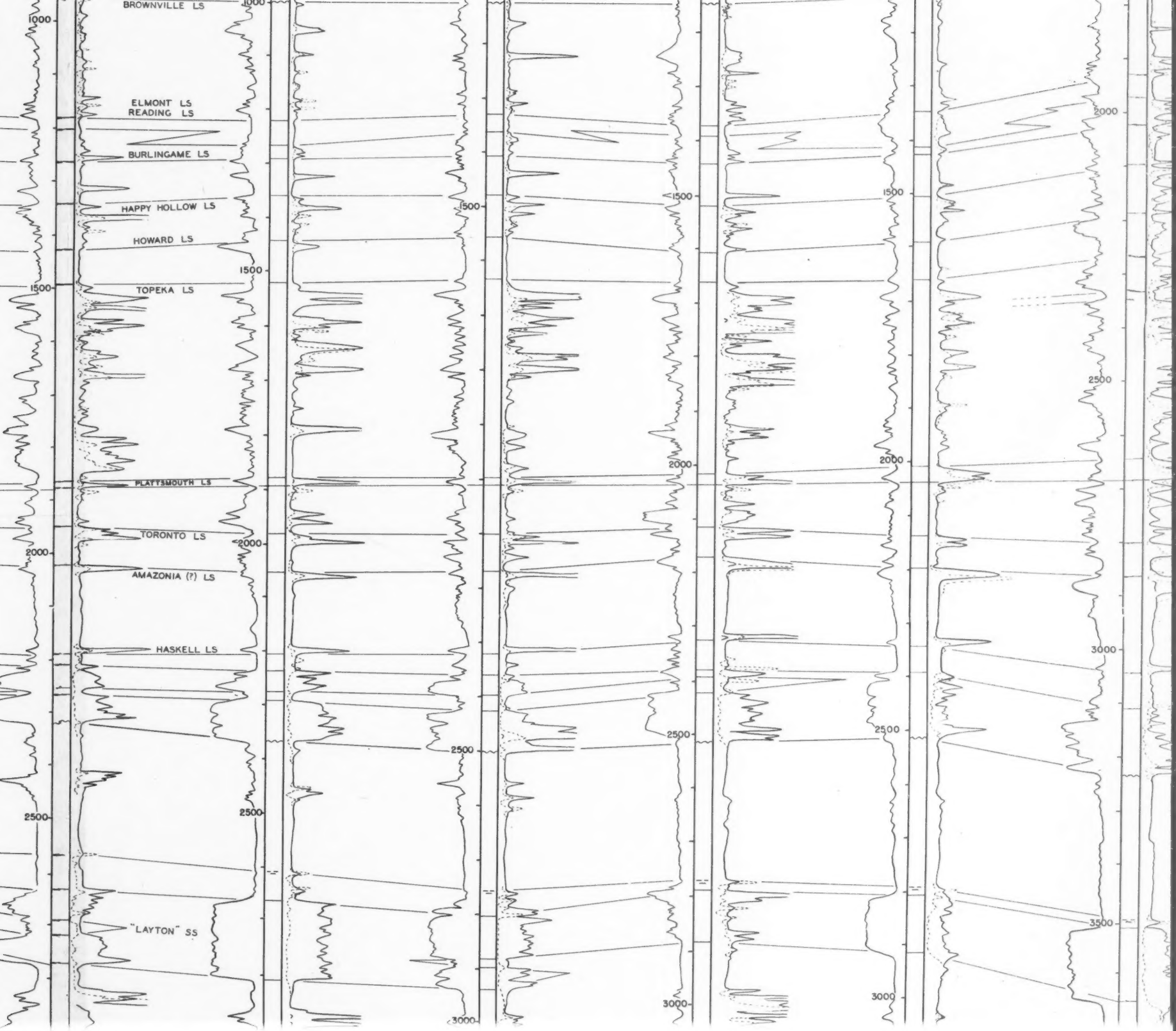
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HASKELL LS
"LAYTON" SS
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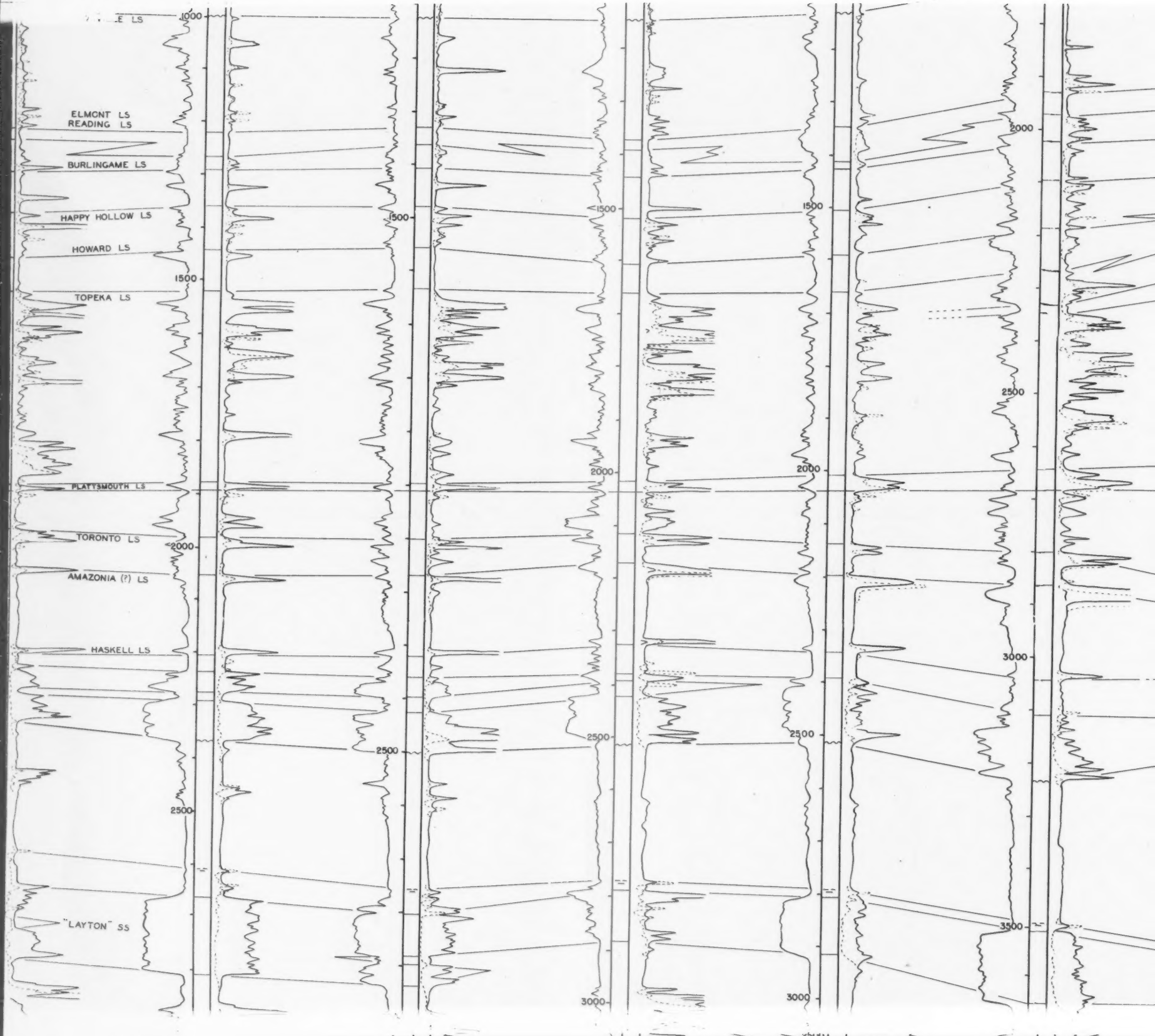
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PLATTSMOUTH LS
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AMAZONIA (?) LS
HASKELL LS
"LAYTON" SS
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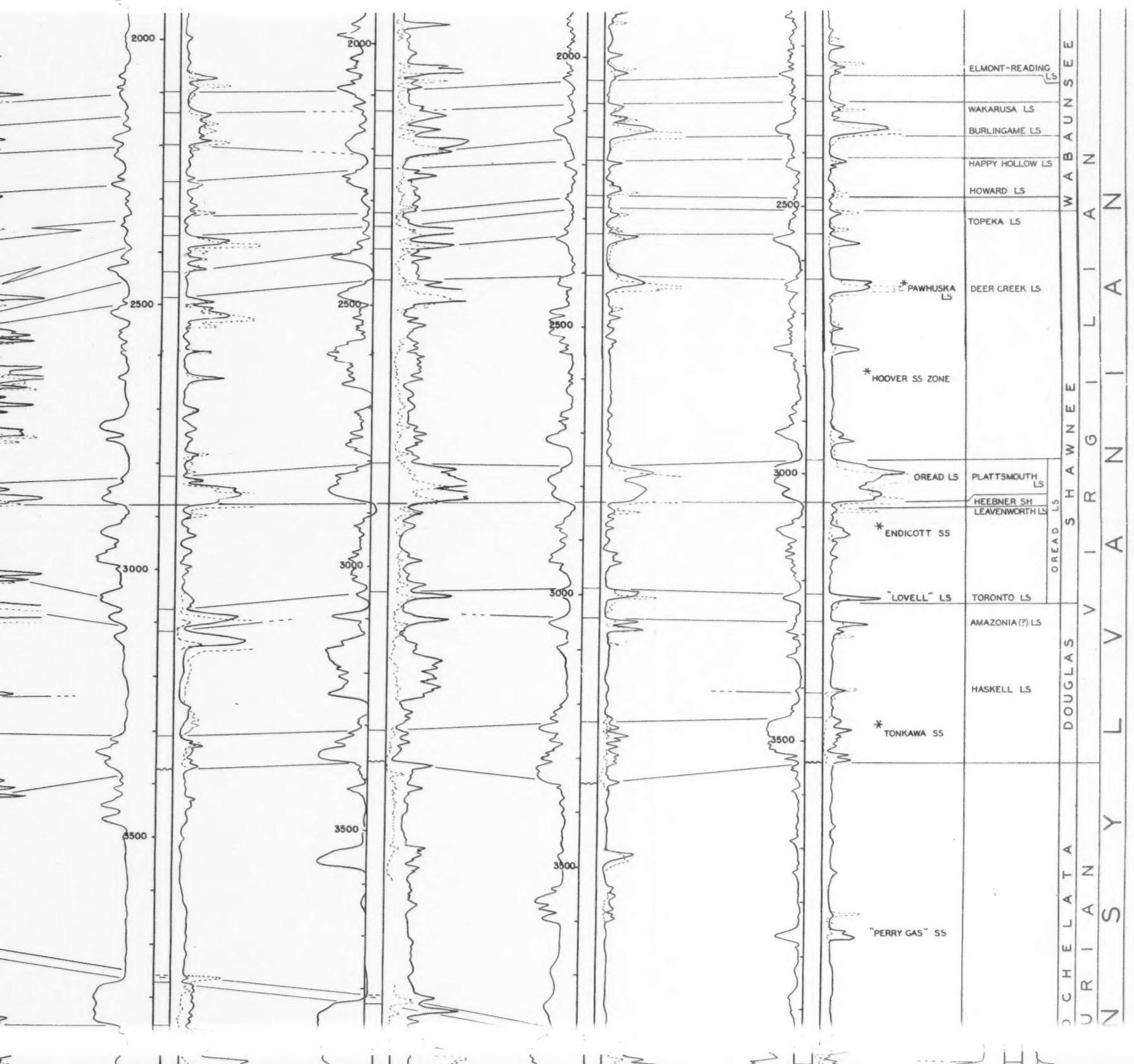
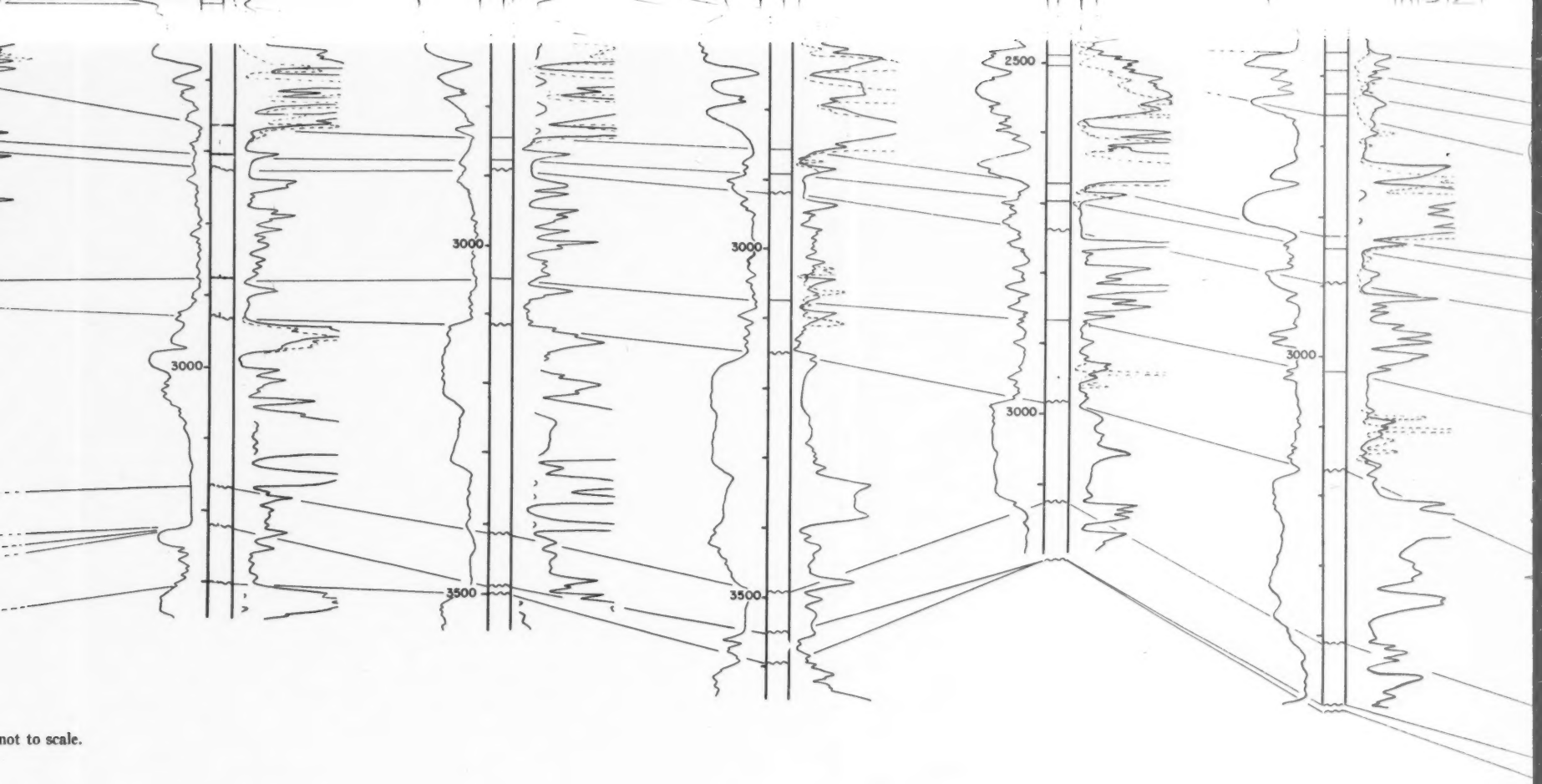
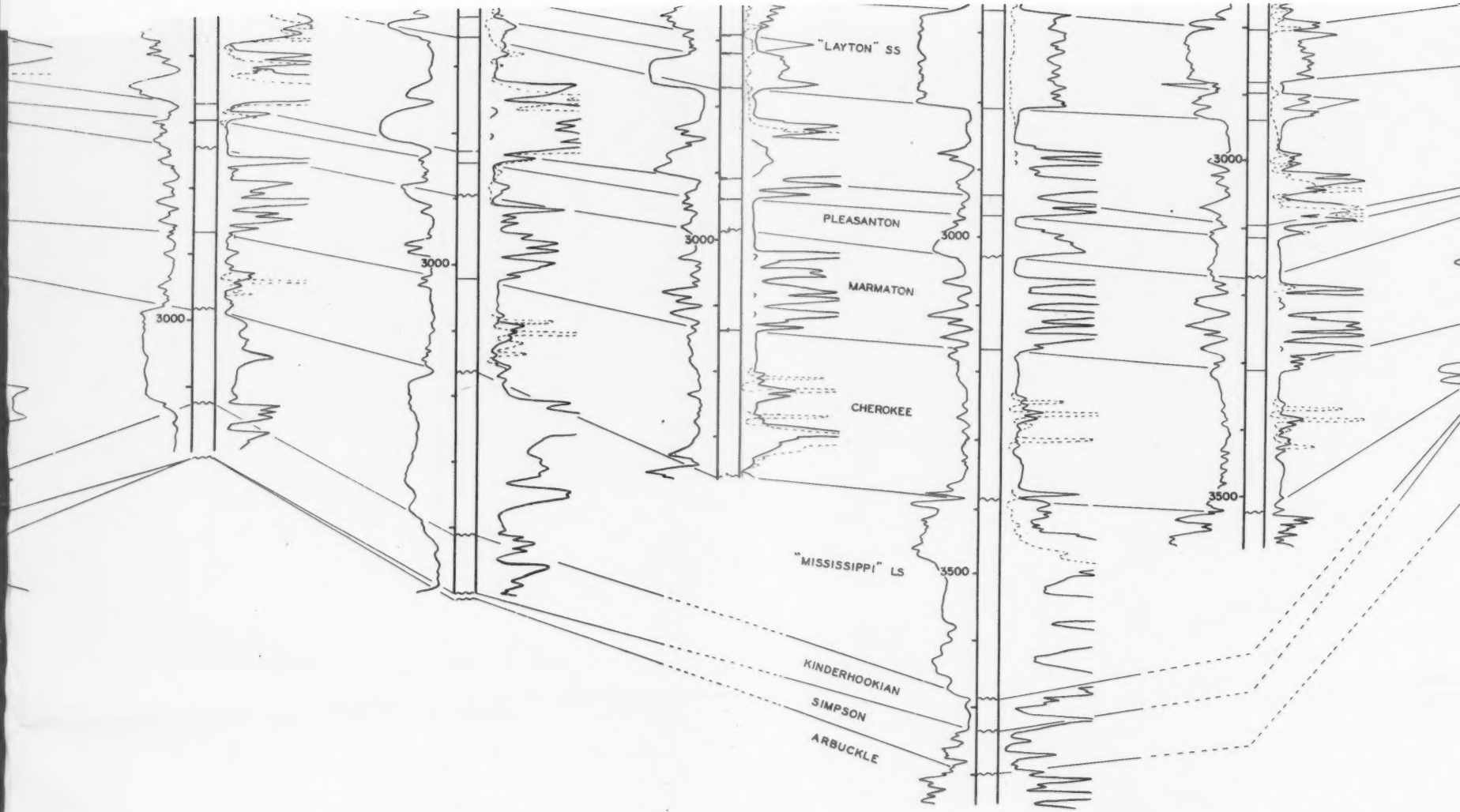
3000
3500


2000
2500
3000
3500
ELMONT-READING LS
WAKARUSA LS
BURLINGAME LS
HAPPY HOLLOW LS
HOWARD LS
TOPEKA LS
*PAWHUSKA LS
DEER CREEK LS
*HOOVER SS ZONE
OREAD LS
PLATTSMOUTH LS
HEEBNER SH
LEAVENWORTH LS
*ENDICOTT SS
"LOVELL" LS
TORONTO LS
AMAZONIA (?) LS
HASKELL LS
*TONKAWA SS
"PERRY GAS" SS
WABAUNSEE
SHAWNEE
OREAD LS
DOUGLAS
VIRGILIAN
SYLVANIAN
CHELATA
URIAN

PL. I.—Subsurface geologic cross section *AB* from Marion County, Kansas, to Garfield County, Oklahoma. For location of cross section and wells see Figure 2. Horizontal distances not to scale. Datum, base of Plattsmouth limestone member of Oread limestone. Beds marked with asterisk (*) are terms used in Tonkawa pool reports.

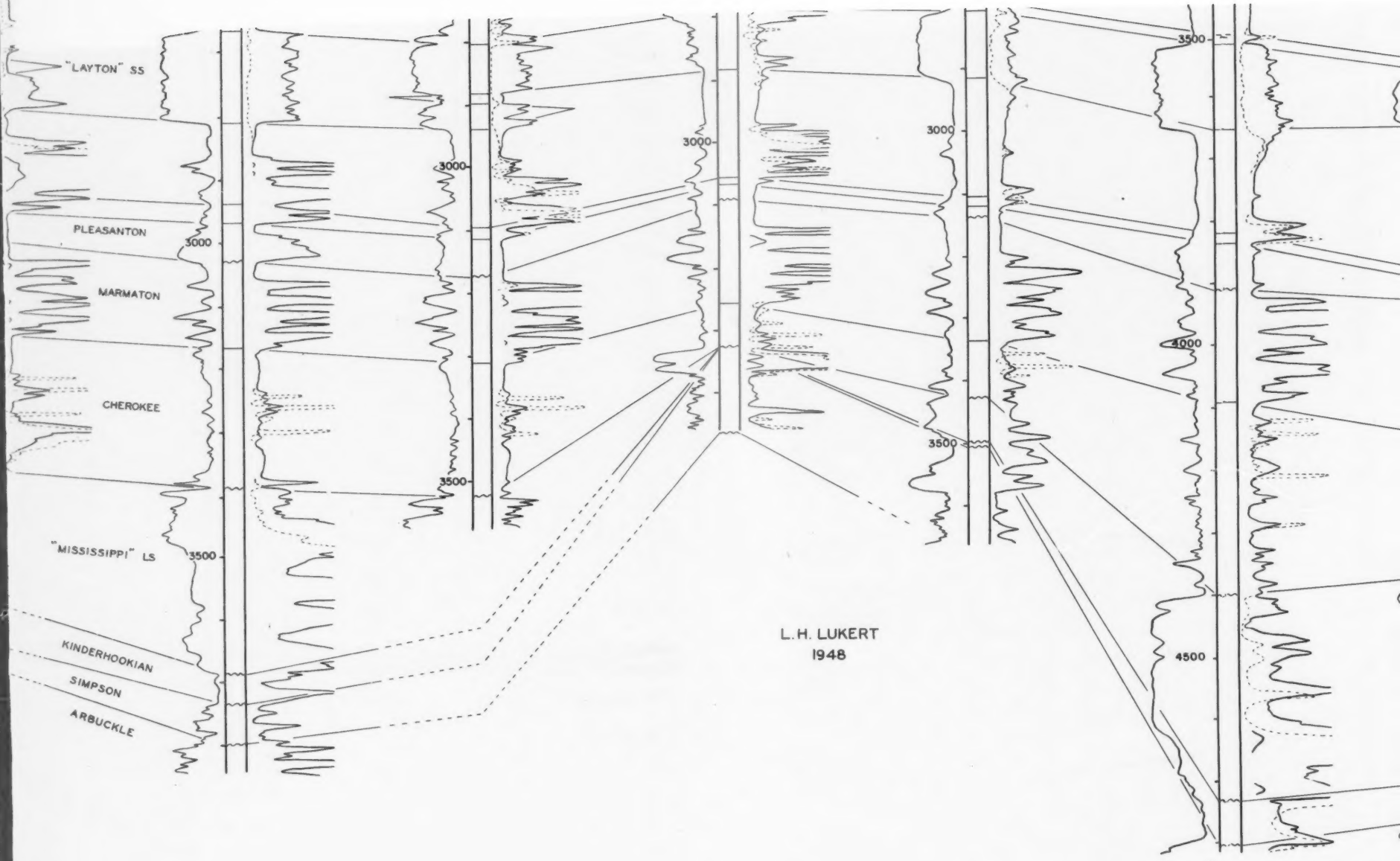


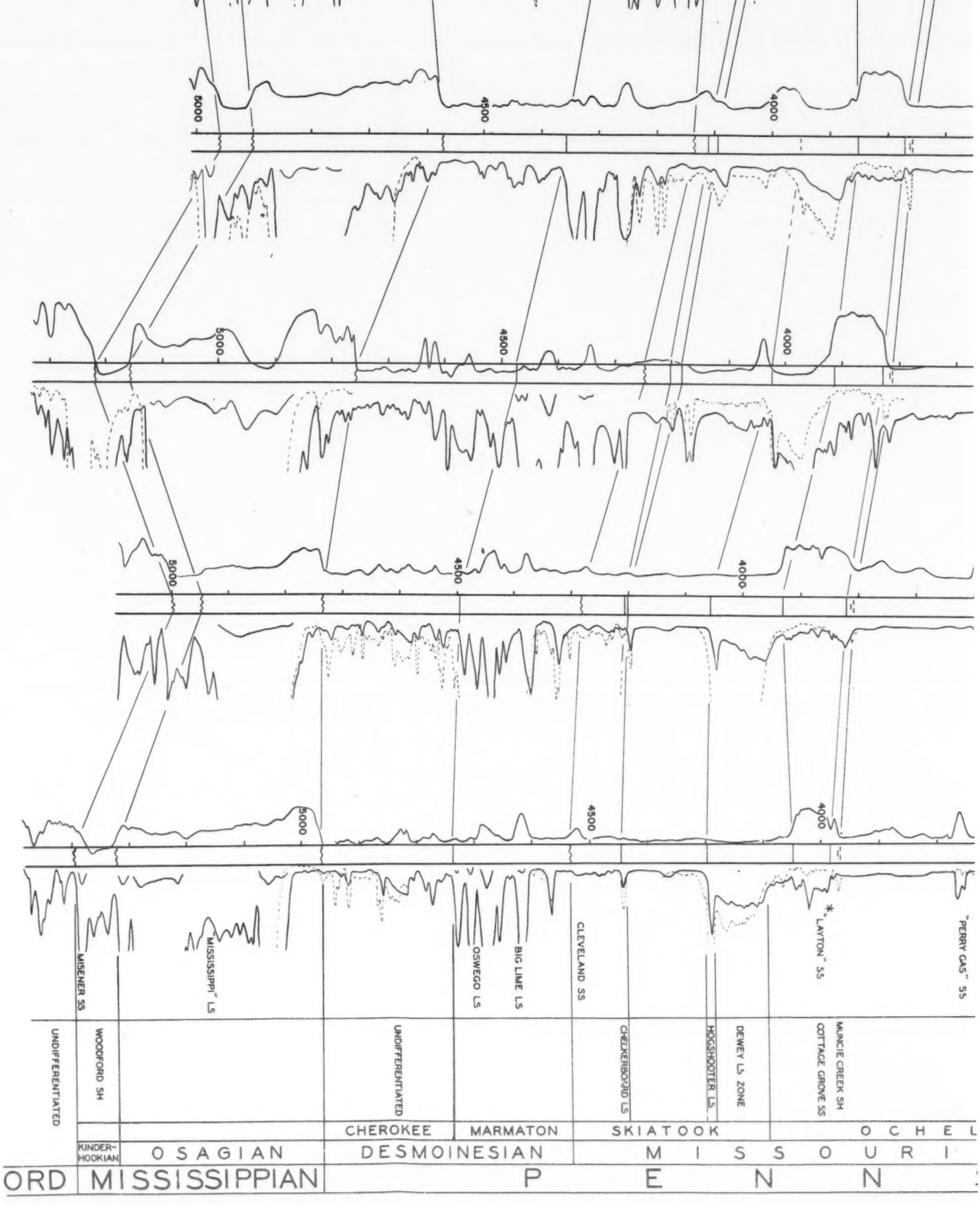
not to scale.

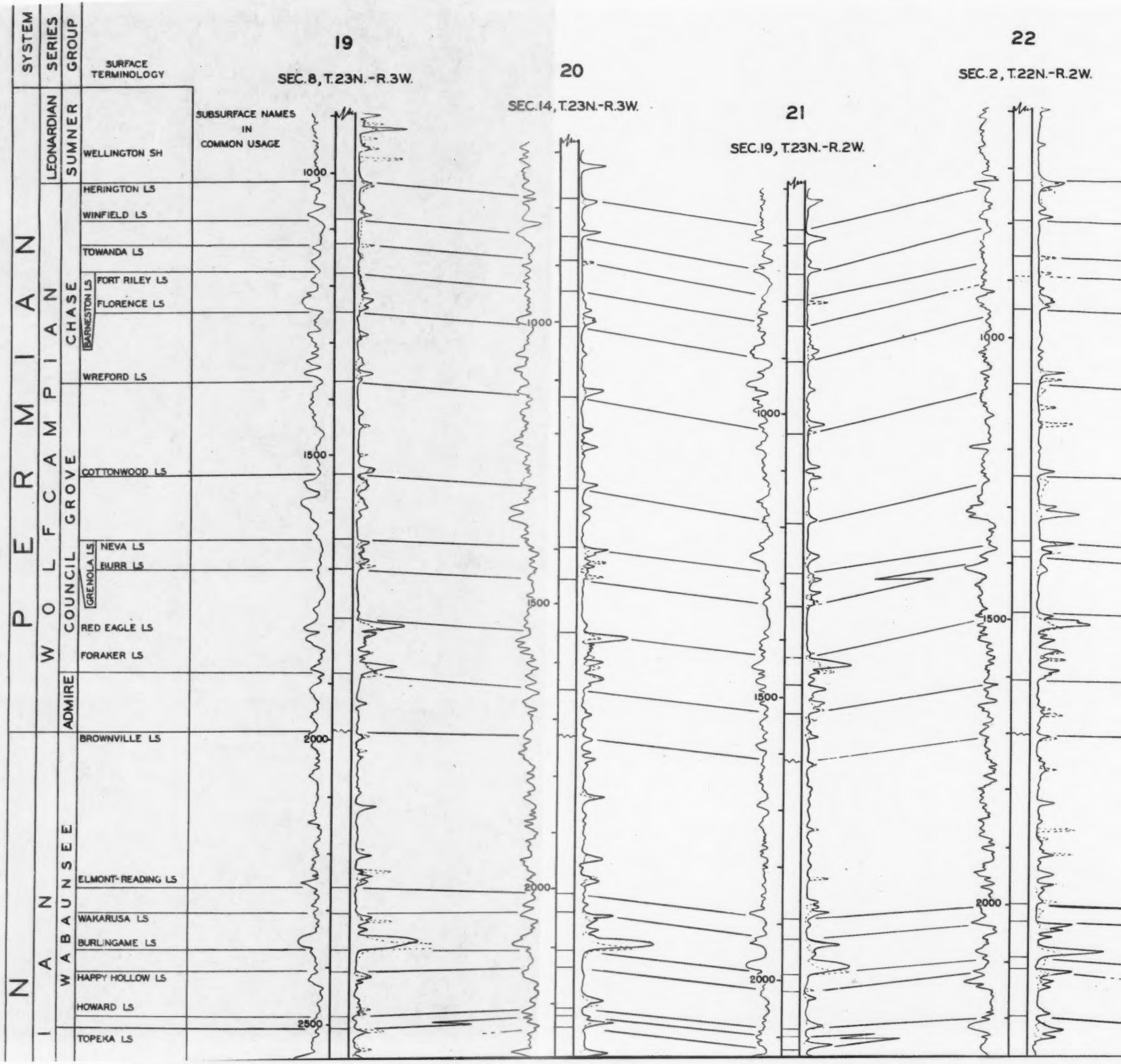

"LAYTON" SS
PLEASANTON
MARMATON
CHEROKEE
"MISSISSIPPI" LS
KINDERHOOKIAN
SIMPSON
ARBUCKLE
3000
3000
3000
3000
3000
3500
3500

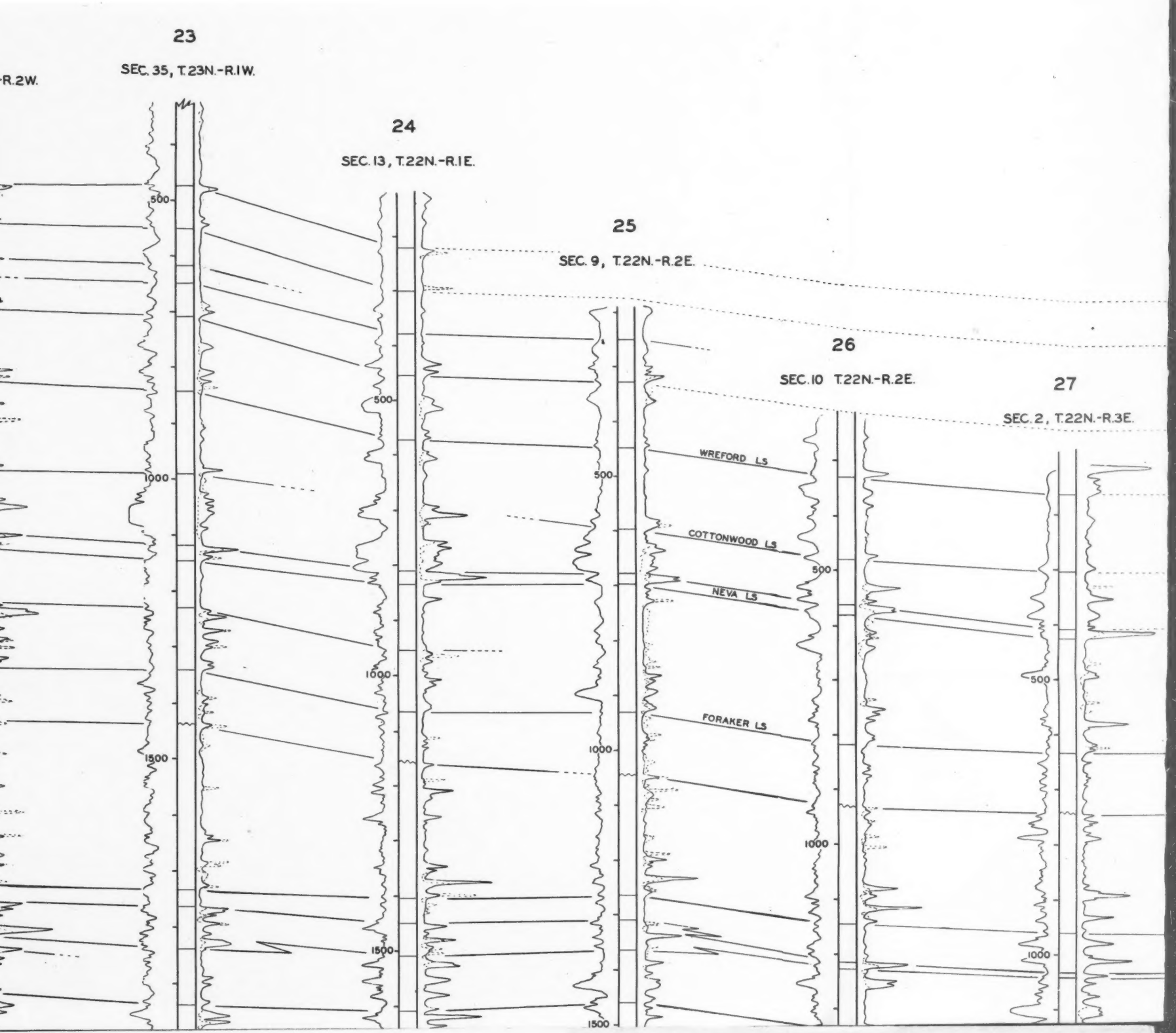
3000
3000
3500
4000
4000
4000
3500
4500
4500
4500
5000
5000
5000
L. H. LUKERT
1948

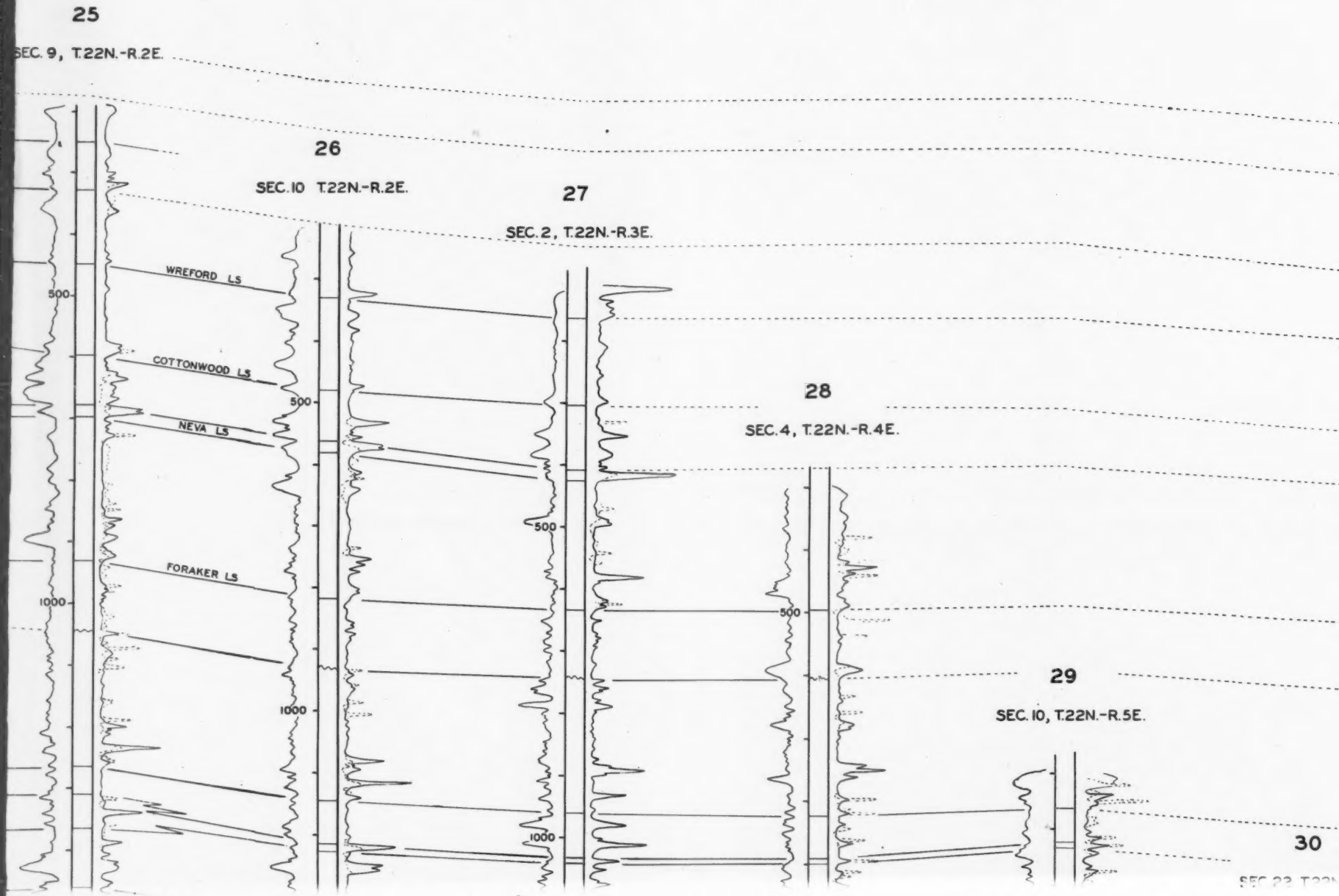
"PERRY GAS" SS

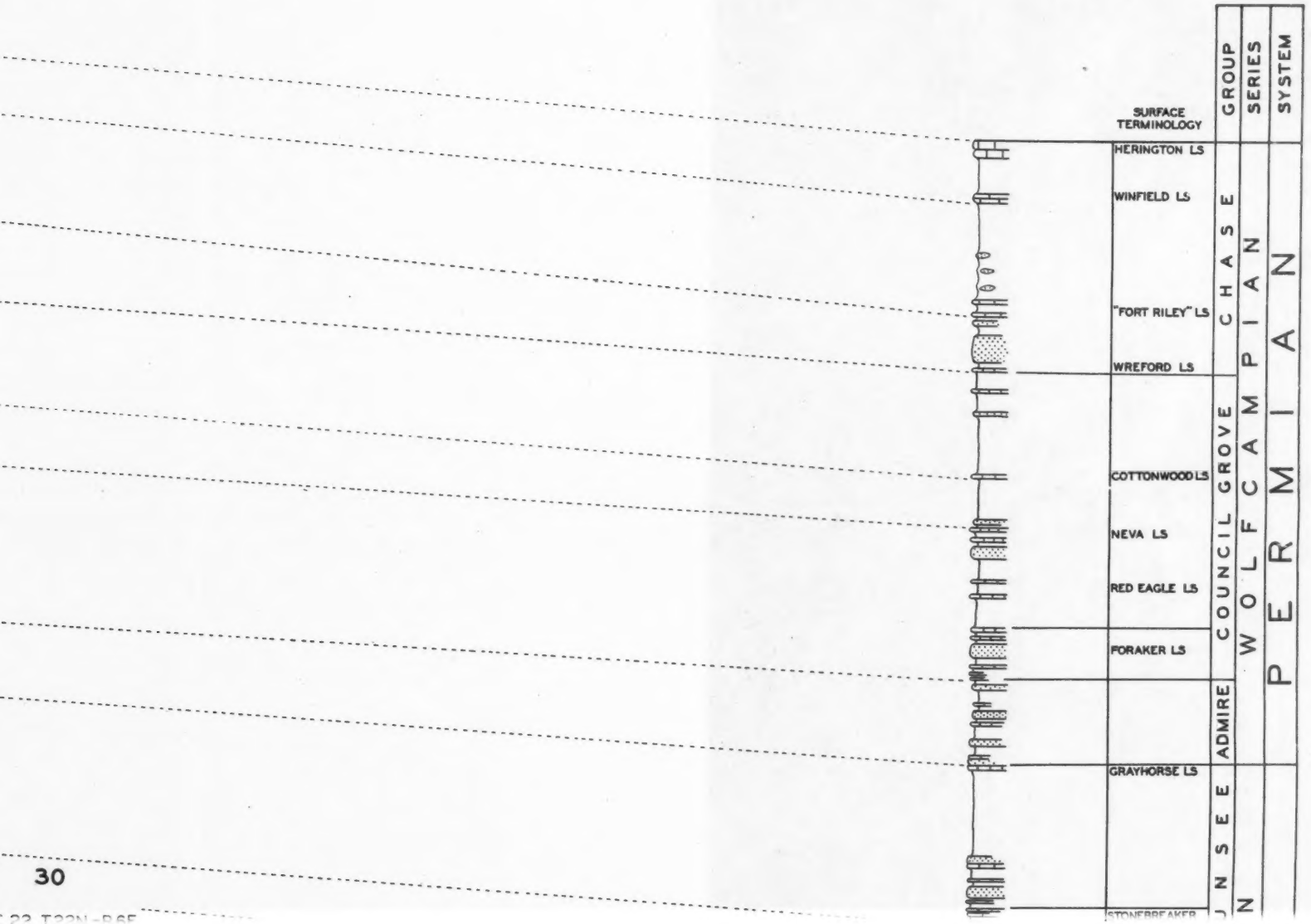

"LAYTON" SS
PLEASANTON
MARMATON
CHEROKEE
"MISSISSIPPI" LS
KINDERHOOKIAN
SIMPSON
ARBUCKLE
3000
3500
4000
4500
L.H. LUKERT
1948

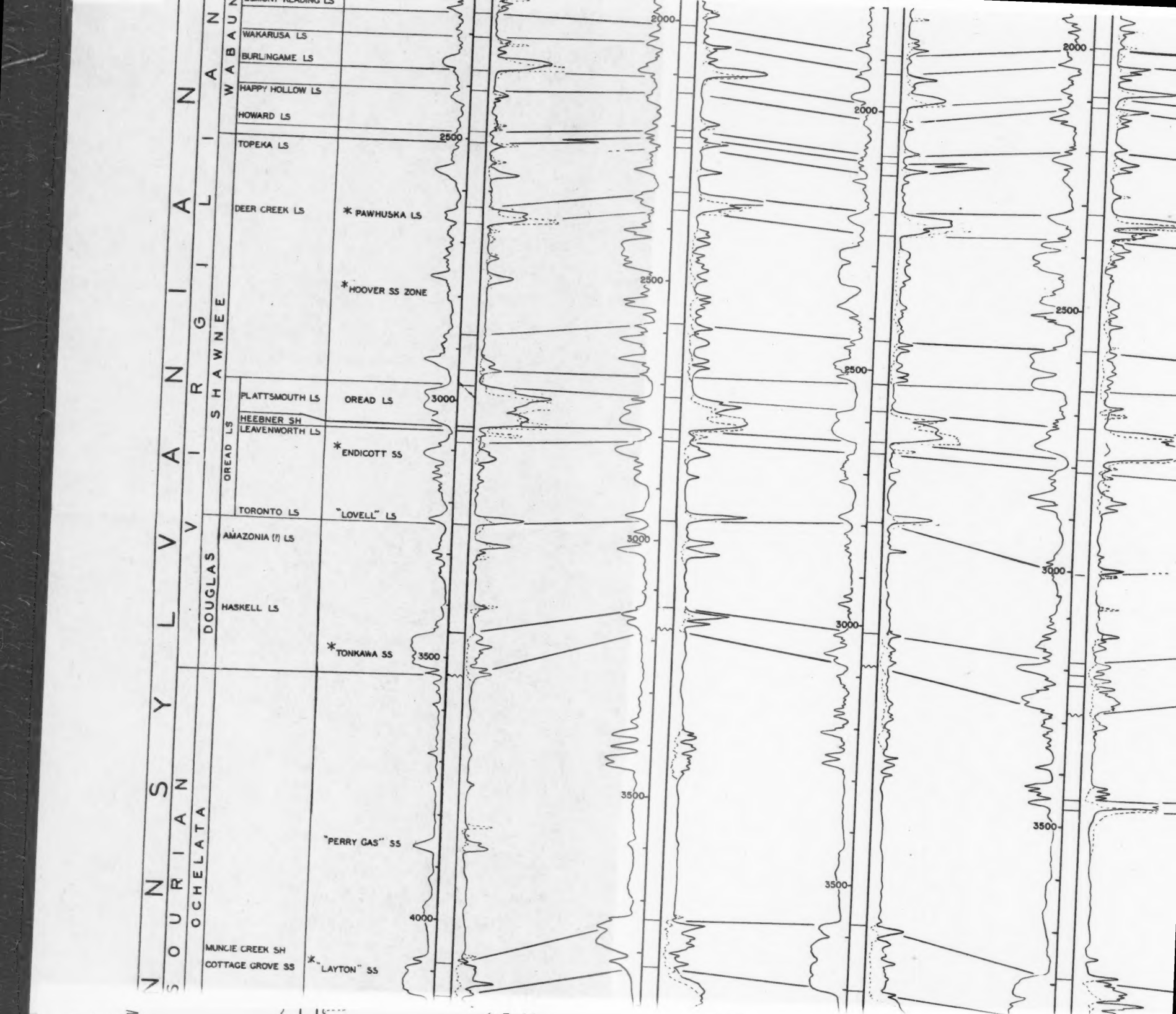

5000
4500
4000
MISENER SS
"MISSISSIPPI" LS
OSWEGO LS
BIG LIME LS
CLEVELAND SS
"LAYTON" SS
"PERRY GAS" SS
UNDIFFERENTIATED
WOODFORD SH
UNDIFFERENTIATED
CHECKERBOARD LS
HOGSHOOTER LS
DEWEY LS ZONE
COTTAGE GROVE SS
MUNCIE CREEK SH
CHEROKEE
MARMATON
SKIATOOK
OCHEL
KINDER-HOOKIAN
OSAGIAN
DESMOINESIAN
MISSOURI
ORD
MISSISSIPPIAN
PENN

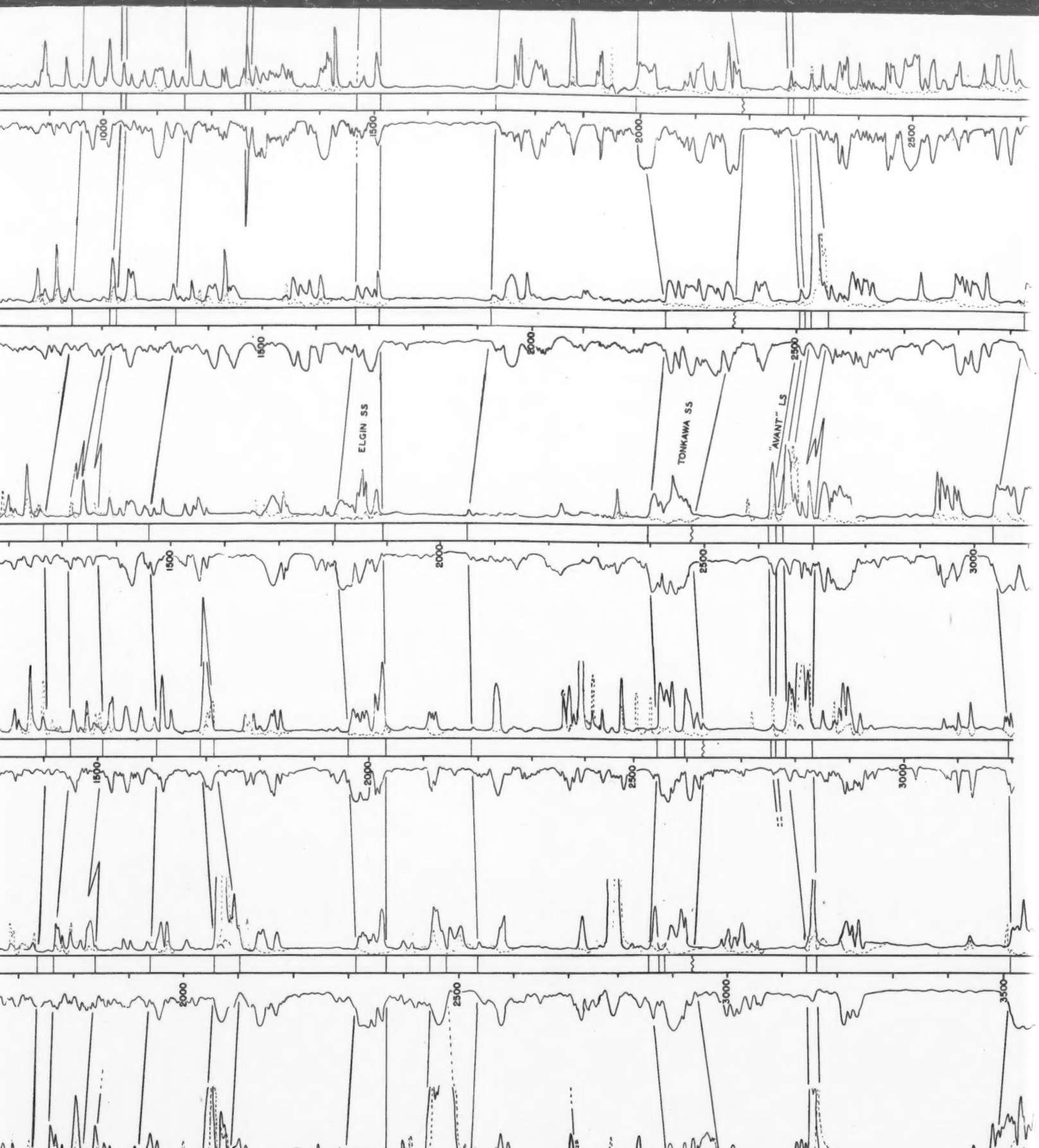

SYSTEM
SERIES
GROUP
SURFACE TERMINOLOGY
SUBSURFACE NAMES IN COMMON USAGE
PERMIAN
LEONARDIAN
SUMNER
WELLINGTON SH
WOLFCAMPIAN
CHASE
HERINGTON LS
WINFIELD LS
TOWANDA LS
FORT RILEY LS
BARNESTON LS
FLORENCE LS
WREFORD LS
COUNCIL GROVE
COTTONWOOD LS
GRENOLA LS
NEVA LS
EIURR LS
RED EAGLE LS
FORAKER LS
ADMIRE
BROWNVILLE LS
NAMAN
WABAUNSEE
ELMONT-READING LS
WAKARUSA LS
BURLINGAME LS
HAPPY HOLLOW LS
HOWARD LS
TOPEKA LS
19
SEC.8, T.23N.-R.3W.
20
SEC.14, T.23N.-R.3W.
21
SEC.19, T.23N.-R.2W.
22
SEC.2, T.22N.-R.2W.
1000
1500
2000
2500

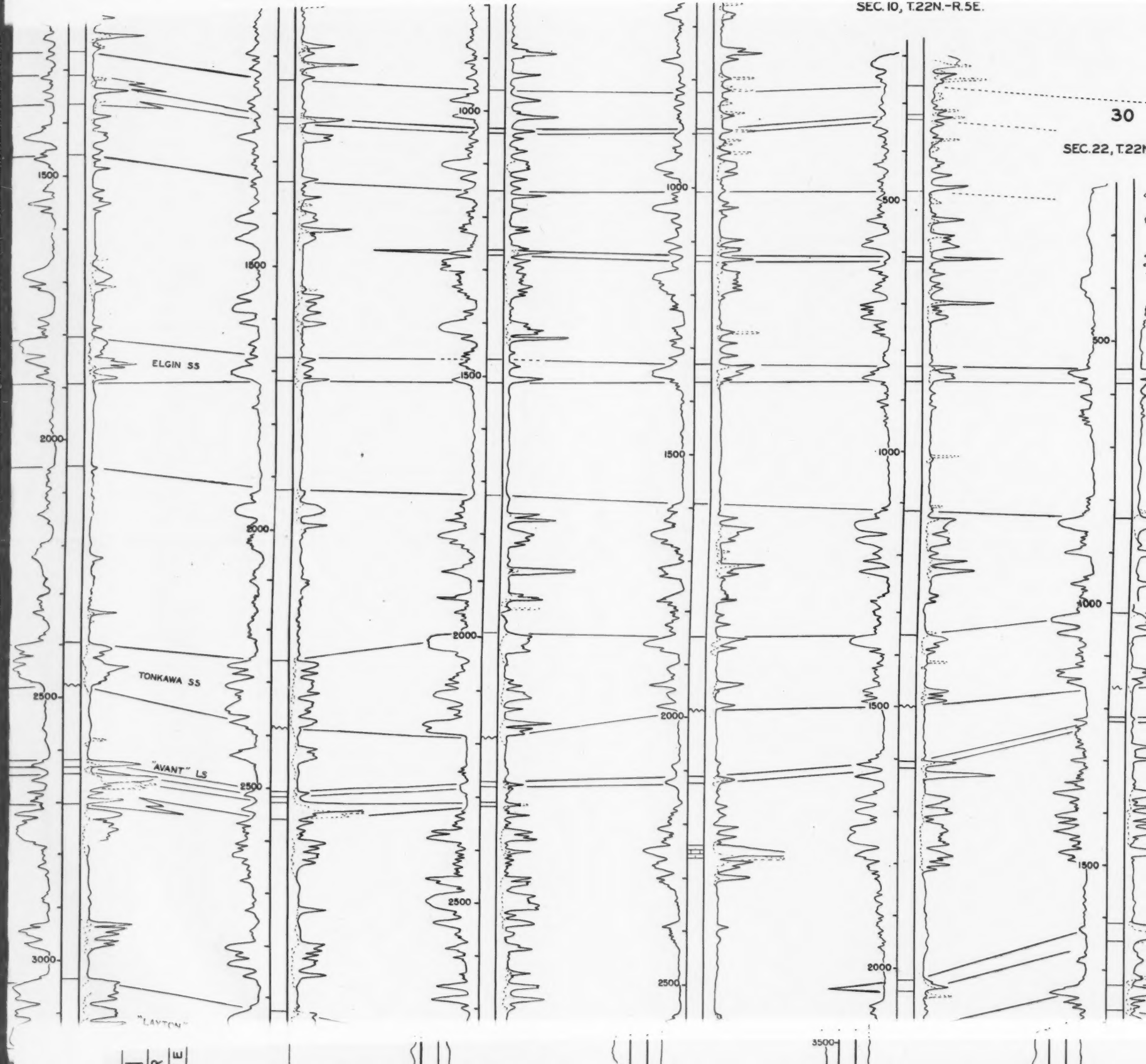

-R.2W.
23
SEC. 35, T.23N.-R.1W.
24
SEC. 13, T.22N.-R.1E.
25
SEC. 9, T.22N.-R.2E.
26
SEC. 10 T.22N.-R.2E.
27
SEC. 2, T.22N.-R.3E.
WREFORD LS
COTTONWOOD LS
NEVA LS
FORAKER LS
500
1000
1500

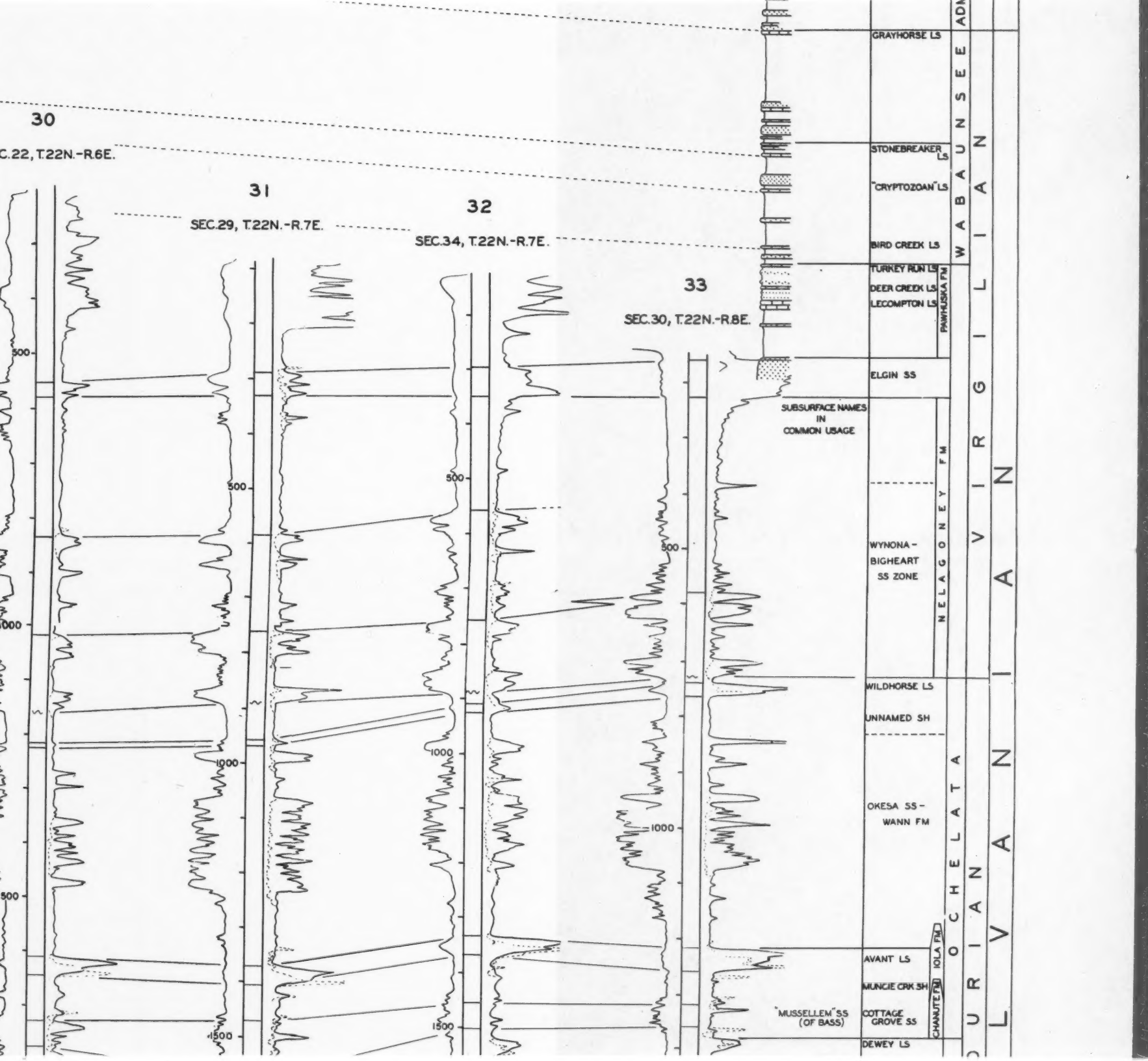

25
SEC. 9, T.22N.-R.2E.
26
SEC. 10 T.22N.-R.2E.
27
SEC. 2, T.22N.-R.3E.
28
SEC. 4, T.22N.-R.4E.
29
SEC. 10, T.22N.-R.5E.
30
WREFORD LS
COTTONWOOD LS
NEVA LS
FORAKER LS
500
1000
ELMONT-READING LS
2000

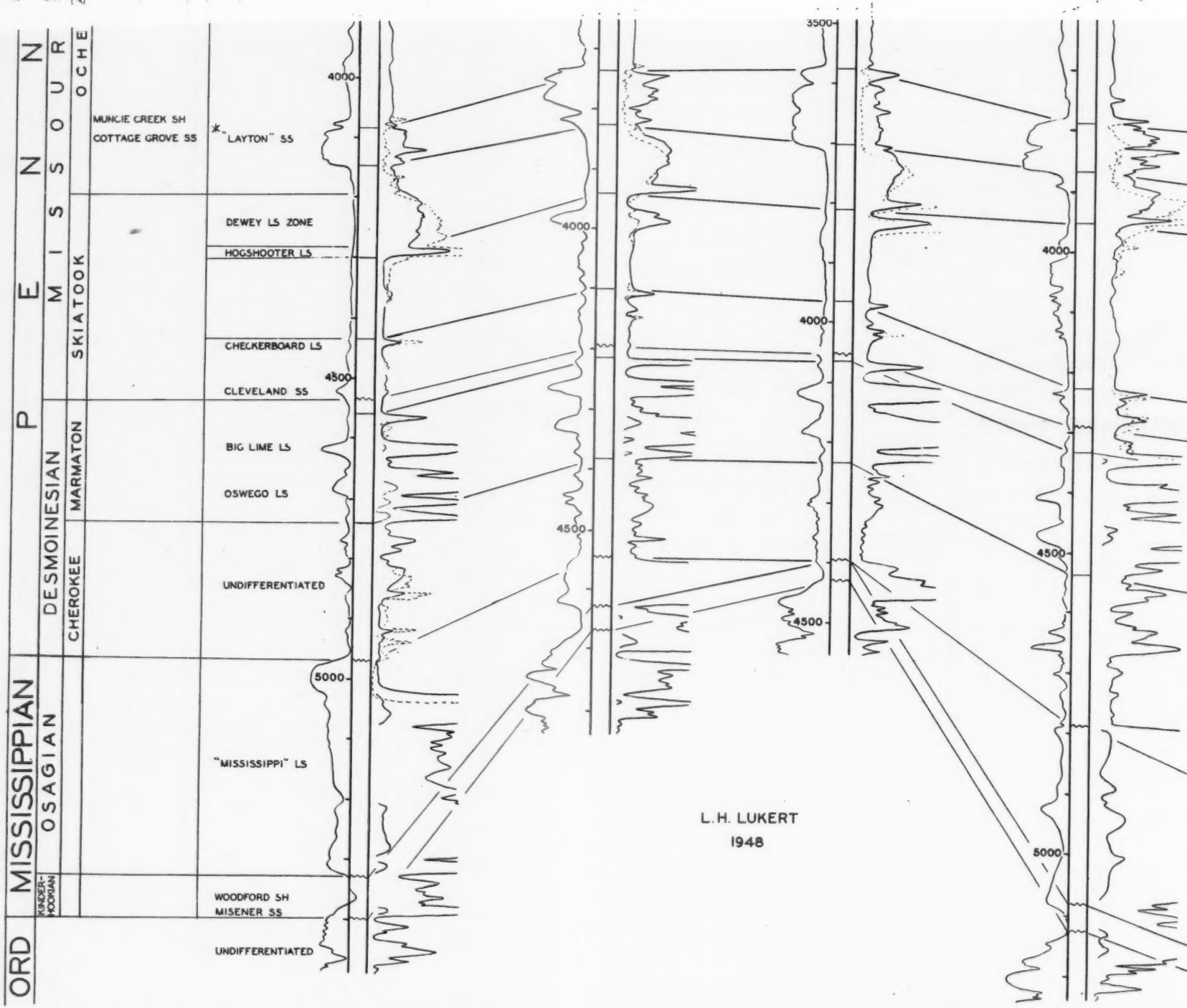

SURFACE TERMINOLOGY
GROUP
SERIES
SYSTEM
HERINGTON LS
WINFIELD LS
"FORT RILEY" LS
WREFORD LS
COTTONWOOD LS
NEVA LS
RED EAGLE LS
FORAKER LS
GRAYHORSE LS
STONEBREAKER
CHASE
COUNCIL GROVE
ADMIRE
WOLFCAMPIAN
PERMIAN


PENNSYLVANIAN
VIRGILIAN
SHAWNEE
WABAUNSEE
DOUGLAS
SOURIAN
OCHELATA
OREAD LS
WAKARUSA LS
BURLINGAME LS
HAPPY HOLLOW LS
HOWARD LS
TOPEKA LS
DEER CREEK LS
PLATTSMOUTH LS
HEEBNER SH
LEAVENWORTH LS
TORONTO LS
AMAZONIA (?) LS
HASKELL LS
MUNCIE CREEK SH
COTTAGE GROVE SS
* PAWHUSKA LS
* HOOVER SS ZONE
OREAD LS
* ENDICOTT SS
"LOVELL" LS
* TONKAWA SS
"PERRY GAS" SS
* "LAYTON" SS
2000
2500
3000
3500
4000
SEC. 10, T.22N.-R.5E.

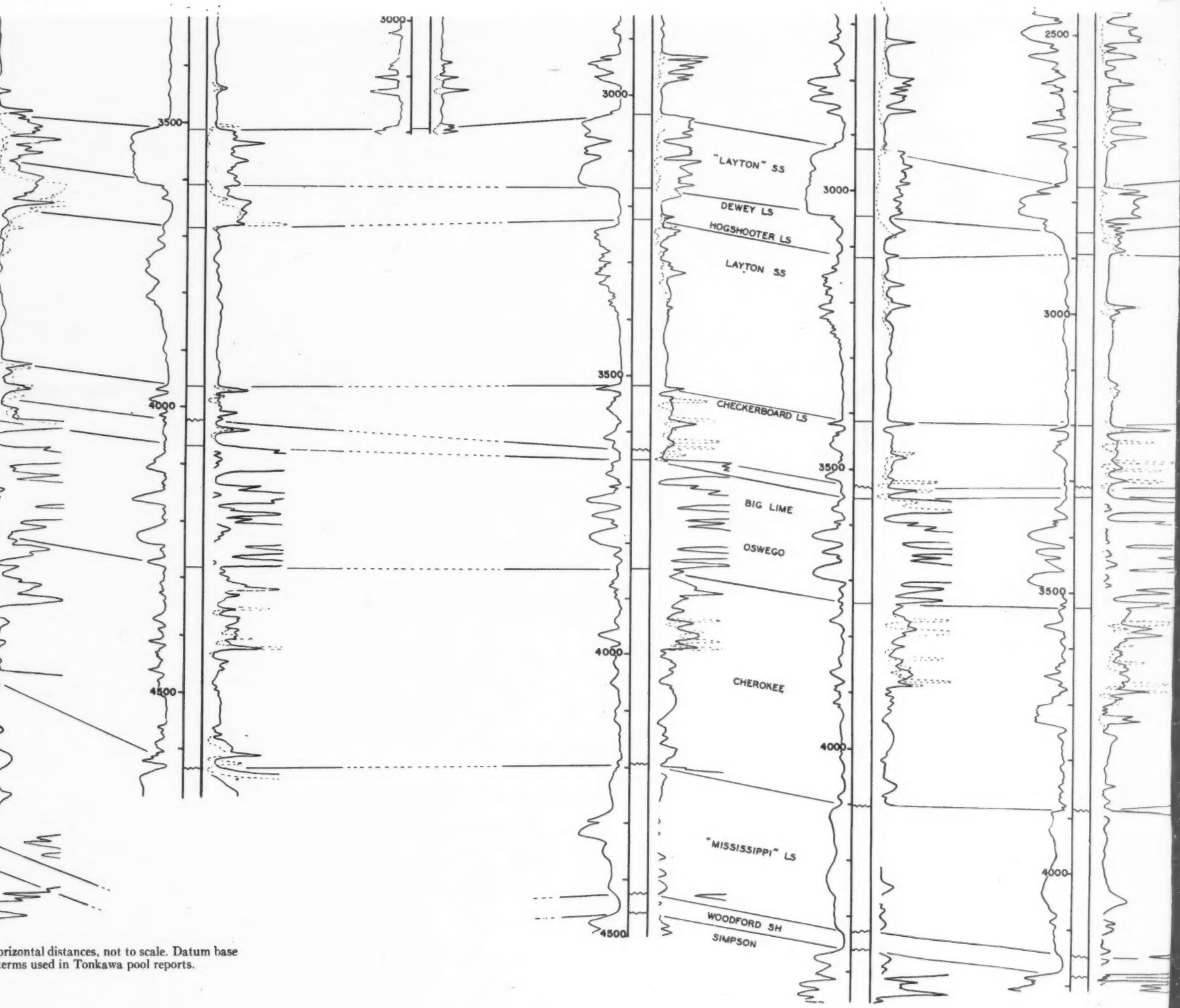

1000
1500
2000
2500
ELGIN SS
TONKAWA SS
"AVANT" LS
3000
3500
GRAYHORSE LS


SEC. 10, T.22N.-R.5E.
30
SEC. 22, T.22N
ELGIN SS
TONKAWA SS
"AVANT" LS
"LAYTON"
1000
1500
2000
2500
3000
3500
500

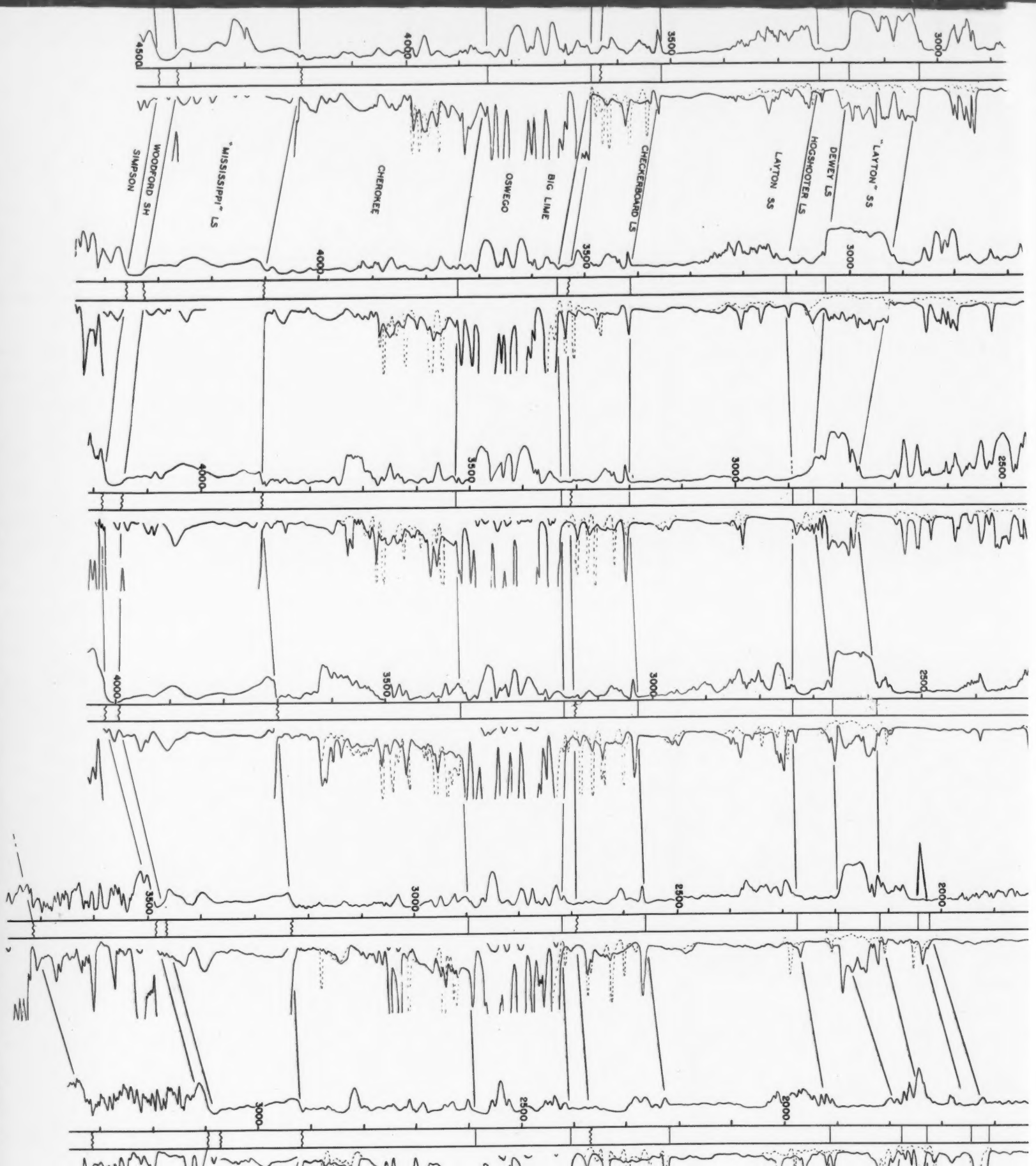

30
C.22, T.22N.-R.6E.
31
SEC.29, T.22N.-R.7E.
32
SEC.34, T.22N.-R.7E.
33
SEC.30, T.22N.-R.8E.
500
1000
1500
GRAYHORSE LS
STONEBREAKER LS
"CRYPTOZOAN" LS
BIRD CREEK LS
TURKEY RUN LS
DEER CREEK LS
LECOMPTON LS
PAWHUSKA FM
ELGIN SS
SUBSURFACE NAMES IN COMMON USAGE
WYNONA - BIGHEART SS ZONE
NELAGONEY FM
WILDHORSE LS
UNNAMED SH
OKESA SS - WANN FM
AVANT LS
MUNCIE CRK SH
IOLA FM
CHANUTE FM
COTTAGE GROVE SS
"MUSSELLEM" SS (OF BASS)
DEWEY LS
WABAUNSEE
ADMIRE
VIRGILIAN
OCHELATA
DURIAN
LVANIAN
3000
2500

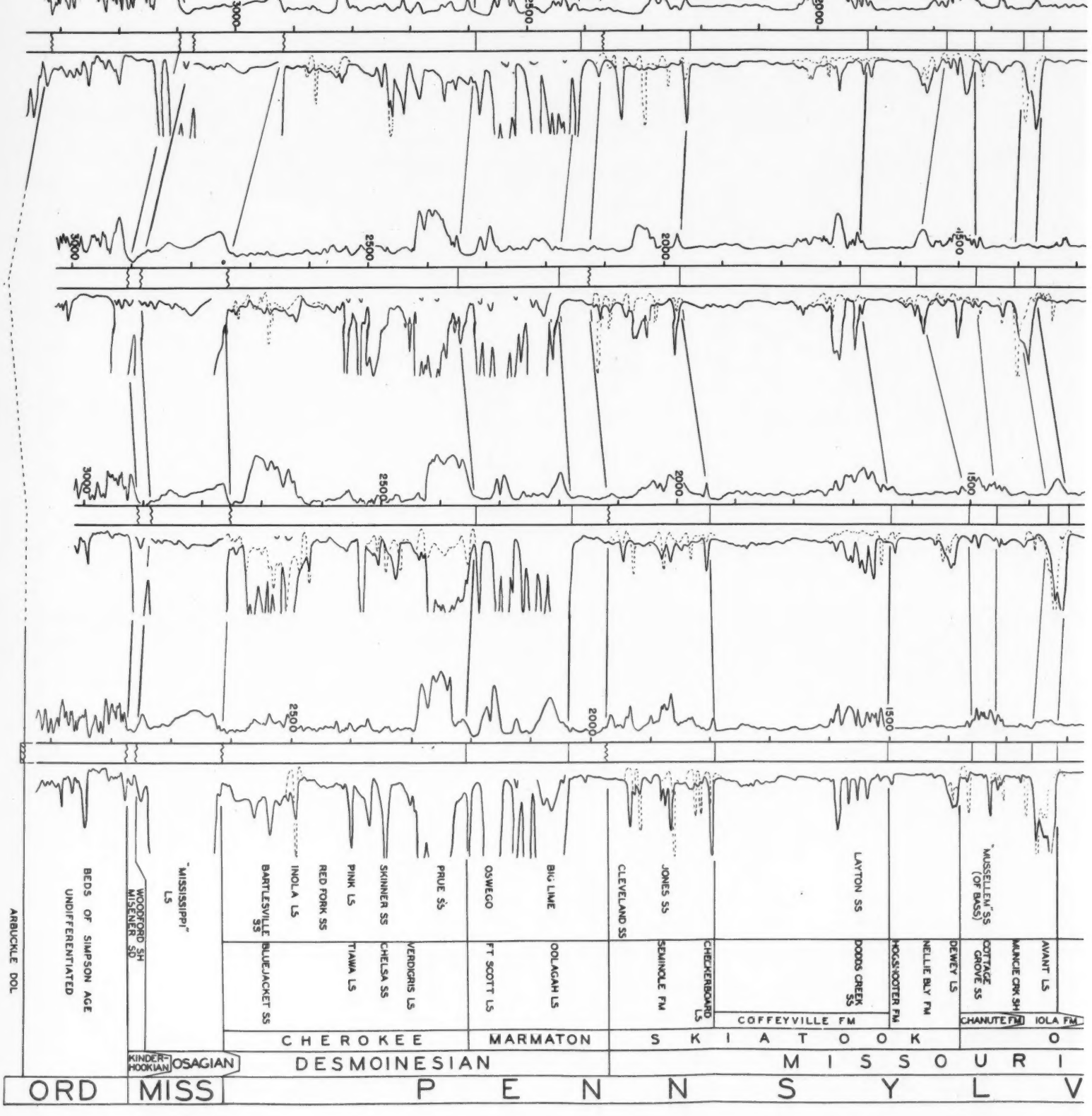


PL. II.—Subsurface geologic cross section *BC* from Garfield County to Osage County, Oklahoma. For location of cross section and wells see Figure 2. Well numbers refer to Table I. Horizontal dista
of Elgin sandstone. Surface section at well No. 33 adopted from studies by A. N. Murray, Noel Evans, G. C. Clark, and C. L. Cooper. Beds marked with asterisk (*) are terms used in



orizontal distances, not to scale. Datum base
erms used in Tonkawa pool reports.


SIMPSON
WOODFORD SH
"MISSISSIPPI" LS
CHEROKEE
OSWEGO
BIG LIME
CHECKERBOARD LS
LAYTON SS
HOGSHOOTER LS
DEWEY LS
"LAYTON" SS
4500
4000
3500
3000
2500
2000


3000
2500
2000
1500
ARBUCKLE DOL
BEDS OF SIMPSON AGE UNDIFFERENTIATED
WOODFORD SH
MISENER SD
"MISSISSIPPI" LS
BARTLESVILLE SS
BLUEJACKET SS
INOLA LS
RED FORK SS
PINK LS
TIAWA LS
SKINNER SS
CHELSA SS
PRUE SS
VERDIGRIS LS
OSWEGO
FT SCOTT LS
BIG LIME
OOLAGAH LS
CLEVELAND SS
JONES SS
SEMINOLE FM
CHECKERBOARD LS
LAYTON SS
DOODS CREEK SS
COFFEYVILLE FM
HOGSHOOTER FM
NELLIE BLY FM
DEWEY LS
"MUSSELLEN" SS (OF BASS)
COTTAGE GROVE SS
MUNCIE CRK SH
CHANUTE FM
AVANT LS
IOLA FM
CHEROKEE
MARMATON
SKIATOOK
KINDERHOOKIAN
OSAGIAN
DESMOINESIAN
MISSOURI
ORD
MISS
PENNSYLV

The relationship of these sandy beds with those at the equivalent horizon in well No. 6 and wells at the south is not clear because southward the Westphalia(?) limestone can not be recognized. It seems that where the Westphalia(?) limestone is absent, a well developed sandstone, known in the subsurface as the Stalnaker, occupies the interval between the Haskell and possibly truncated limestones of Missourian age. Such a condition is indicated at well No. 6. This study suggests that the Stalnaker is Virgilian in age and in part equivalent to beds occupying the position of the Tonganoxie sandstone.

Here and elsewhere along its strand line the northern limit of the Stalnaker sandstone occurs in the same area that marks the southern limit of the Missourian limestones. This coincidental feature has undoubtedly caused many workers to consider the Stalnaker sandstone as a facies change of the Missourian limestones.

On cross section *AB*, well No. 12 (SW. ¼, SW. ¼, NW. ¼, Sec. 11, T. 35 S., R. 2 E., Sumner County, Kansas) is herein considered to be a type well for the Stalnaker[19] sandstone. The name was derived from the Stalnaker farm where on April 20, 1914, a 7 million cubic-foot gas well was completed in a zone at 2,380–2,397 feet in the northwest corner of the SE. ¼, Sec. 11, T. 35 S., R. 2 E.

Farther south in Oklahoma this sandstone is known as Tonkawa from the name of a lease in the Tonkawa pool in T. 24 and 25 N., R. 1 W., Noble and Kay counties, Oklahoma. This sandstone has been traced into Osage County where it is considered a part of the Bigheart sandstone section of Virgilian age.[20] In the cross sections this sandstone zone attains a thickness of 125 feet and though it appears somewhat massive, it is generally interbedded with shale partings.

A study of well samples along the cross sections indicates that the Stalnaker-Tonkawa zone commonly contains a zone of coarser and unevenly sorted sand. This coarser sand is characteristic and widespread. A zone from 2,460 to 2,480 feet in well No. 12 contains unevenly sized fragments of light-colored weathered chert. A similar type of weathered chert occurs in well No. 19 from 3,520 to 3,540 feet and also in the samples from 2,090 to 2,100 feet in a well in the NW. ¼, NW. ¼, SW. ¼, Sec. 1, T. 22 N., R. 3 E., Pawnee County, Oklahoma, which is one mile from well No. 27.

The persistent occurrence of the coarse and unevenly sorted sand and the presence of weathered chert in the basal part in widely separated areas is additional evidence for placing the Stalnaker-Tonkawa zone in the Virgilian series. This conclusion also agrees with Moore.[21]

MISSOURIAN SERIES

The Missourian series comprises those rocks from the unconformity at the base of the Virgil to the unconformity at the base of the Pleasanton group in

[19] Anthony Folger, "Development of the Oil and Gas Resources of Kansas in 1928 and 1929," *Kansas Geol. Survey Min. Res. Cir. 2* (February, 1933), p. 61.

[20] R. C. Moore, "Annotated Index of Stratigraphic Terms Applied to Pennsylvanian and Lower Permian Rocks in Southern Kansas and Northern Oklahoma," *Guide Book Eleventh Annual Field Conference, Kansas Geol. Society* (1937), p. 99.

[21] R. C. Moore, personal communication (February 3, 1948).

Kansas, or at the base of the Skiatook group in Oklahoma. Its thickness varies from 390 feet at well No. 1, 1,000 feet at well No. 19, to 1,255 feet at well No. 33.

In Kansas the Missourian series has been divided into the Pedee, Lansing, Kansas City, and Pleasanton groups. In the area of the cross sections, it has not been possible to establish the presence of rocks of the Pedee group although beds of this age are probably present in the eastern part of the area, particularly in Osage County, Oklahoma.

The Lansing-Kansas City groups show their best development in the area of the first few wells in cross section *AB*. At the latitude of Wichita, Kansas (well No. 4), the upper Missourian limestones begin to disappear and at well No. 14 in Oklahoma, nearly all of the prominent limestones disappear. Accordingly, southward from T. 29 S., the Kansas nomenclature of the Missourian rocks becomes less applicable and where the section is traced into Oklahoma, a two-fold division of the Missourian rocks into the Ochelata and Skiatook groups, as used by the Oklahoma Geological Survey, is necessary.

Missourian rocks on the surface in southern Kansas show similar changes from north to south in the nature and thickness of various beds, for as Moore[22] has written,

> . . . groups that appear to be distinct and natural units in the north are no longer clearly differentiated near the Kansas-Oklahoma boundary. . . . there is actually good reason to abandon the group divisions Bourbon, Bronson, Kansas (Kansas City), Lansing, and Pedee at about Twp. 31 S., in Kansas. For townships farther south in Kansas the northeastern Oklahoma classification of Missouri (Missourian) beds is recommended.

As the writer has not made sufficient study of these Missourian rocks, in the area in which they are characterized by these abrupt facies changes, they are not here subdivided or described in any detail. The following comments may, however, be of interest to the reader.

In Marion County, Kansas, the Lansing-Kansas City groups, which together form a prominent limestone unit, include the rocks from the top of the Stanton limestone to the base of the Hertha limestone.

Cross section *AB* indicates that the change from this predominant limestone section to shales, and then to shales and sandstones, appears first in the Lansing group and finally in the lower part of the Kansas City group.

The Pleasanton group comprises a section of rocks which varies in thickness from 25 to 100 feet. It consists of light- and green-colored shales, a minor amount of limestone, and some fine-grained green silty sandstones. The limestone is sometimes sandy and consists of light-colored, white to green, finely crystalline limestone beds. It commonly contains inclusions of green material thought to be fragments of clay or clay shale. This limestone can be readily recognized by these characteristics and has been followed from well No. 4 to well No. 18. It has not

[22] R. C. Moore, "Upper Carboniferous Rocks of Southeastern Kansas and Northeastern Oklahoma," *Guide Book Eleventh Annual Field Conference, Kansas Geol. Society* (1937), p. 13.

been traced to the outcrop. The sandy beds are correlated with the Hepler sand of the Kansas outcrop section.

The Missourian rocks on the surface in northern Oklahoma which have been recently studied and described by Oakes[23] are divided into the Ochelata and Skiatook groups.

Ochelata group.—The Ochelata group in southern Osage County embraces the beds from the base of the Bigheart sandstone, which marks the base of the Virgilian series, to the base of the Chanute formation which at most places rests on the Dewey limestone. The Ochelata group includes, in descending order, the Wildhorse limestone, Okesa sandstone, and the Wann, Iola, and Chanute formations.

Cross section *CD* (Fig. 5), based on well-sample interpretation, shows the correlations of the upper Missourian beds exposed in T. 22 N., westward to well No. 33 on cross section *BC*. The sequence of beds from the Avant limestone down through the Dewey limestone at locality 38 near Skiatook, Oklahoma, was measured by Borden.[24] For the regional location of cross section *CD*, refer to wells 33–37 on the index map (Fig. 2).

The Wildhorse limestone has been traced westward to well No. 24 where it is the upper part of a well developed limestone zone. From the study of adjacent wells the thickness of this limestone zone shows rapid lateral changes. The greater thicknesses in some areas are thought to be due to a development of calcareous beds within the zone (undifferentiated on the cross section) from the Wildhorse limestone down to and including the Wann formation. This is similar to the conditions found by Oakes[25] on the surface in southern Osage County. This conclusion has not been confirmed through the actual tracing of beds into the outcrop.

In the subsurface in Noble County (wells 22–26), this well developed limestone zone is now erroneously called "Avant" or "Avant-Dewey" by many geologists. In the subsurface it has not been practical to subdivide the Okesa sandstone-Wann formation. From well No. 33 westward to well No. 23, this zone consists predominantly of sandstones and shales. Westward from well No. 23 the Ochelata group is primarily a shale section. The term "Perry gas sand" has been applied by some workers to a sandstone below the so-called "Avant" or "Avant-Dewey zone."

Below the Wann formation occurs the Iola limestone which consists of three members: the Avant limestone, Muncie Creek shale, and the Paola limestone. The Avant limestone occurs as a good limestone from the outcrop westward to well No. 29, beyond which it disappears. The Muncie Creek shale underlies the Avant limestone. On the surface the Muncie Creek shale is generally composed

[23] Malcolm C. Oakes, "Geology and Mineral Resources of Washington County, Oklahoma," *Oklahoma Geol. Survey Bull. 62* (1940), pp. 18–92.
———, *Guide Book Oklahoma City Geol. Society*, Pt. III (1946), pp. 10–17.

[24] Joseph L. Borden, written communication.

[25] Malcolm C. Oakes, *op. cit.*, pp. 10–13 and plate following p. 17.

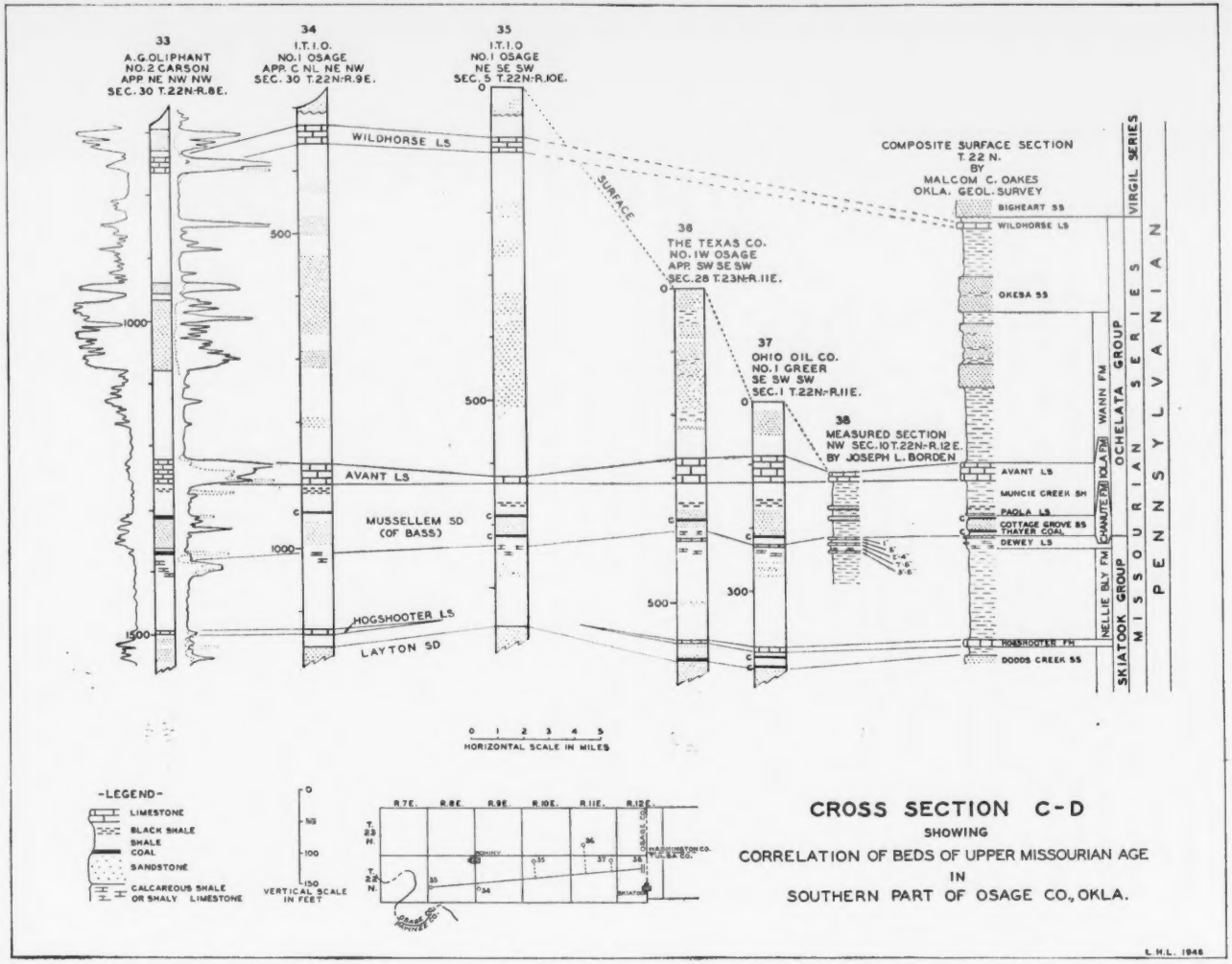


FIG. 5.—Cross section *CD* showing correlation of beds of upper Missourian age in southern part of Osage County, Oklahoma.

of dark clay shale, and in some areas black fissile shale occurs near the base. Oakes[26] reports this black fissile shale in outcrops in T. 23 and 24 N. The black fissile shale was found in many of the wells from which samples were examined. It occurs consistently in wells 6–20, and can be used as a marker bed. In the subsurface, the Paola limestone can seldom be recognized.

The Iola limestone is underlain by the Chanute formation. In the area of the cross section the Cottage Grove sandstone with its associated coals is the important unit which has been identified. The coal underlying this sandstone is known as the Thayer coal. The Cottage Grove sandstone has been traced from the outcrop into the underground and found to be continuous from well No. 37 to well No. 9. It attains a thickness of 135 feet. It generally contains thin shale partings. It is considered the same as the "Mussellem" sand of Bass.[27]

Subsurface studies by the writer have indicated that this sandstone is not correlative with the Mussellem sand of the type area. The "Lexicon of Geologic Names"[28] states that a sand at a depth of 700 or 780 feet above the Layton sand in the Oilton pool in Creek County, Oklahoma, was named Mussellem for its occurrence in wells on land along the Cimarron River 1½ miles south of Oilton, Oklahoma, owned by M. S. Mussellem. The type Mussellem sand occurs in the Ochelata group where it is a part of a sandstone zone above the Avant limestone and is therefore younger than the Cottage Grove sandstone.

In the subsurface the Cottage Grove sandstone has been called "Layton," "Osage Layton," "Layton of Ponca City," or "Peoples" by many workers.

The Chanute formation[29] which forms the lower part of the Ochelata group rests in disconformity on the uneven surface of the underlying Skiatook group. This disconformity is for the most part inconspicuous along the cross sections. However, in eastern Cowley County, Kansas, the disconformity appears to be more prominent. In wells 9–12 the Chanute shows an exceptional development of sandstone and some of the underlying beds belonging to the Skiatook group seem to be absent. It is possible that the lower member or lower part of this sandstone zone may have been deposited in erosional valleys or channels similar to that reported by Moore, Newell, Dott, and Borden,[30] and also by Oakes.[31] If this

[26] Malcolm C. Oakes, "Geology and Mineral Resources of Washington County," *Oklahoma Geol. Survey Bull. 62* (1940), p. 70.

[27] N. W. Bass, "Subsurface Geology and Oil and Gas Resources of Osage County, Oklahoma," *U. S. Geol. Survey Bull. 900-E* (1940), pp. 178, 179.

[28] M. Grace Wilmarth, "Lexicon of Geologic Names of the United States," *U. S. Geol. Survey Bull. 896*, Pt. II (1938), p. 1454.

[29] Malcolm C. Oakes, *Guide Book Oklahoma City Geol. Society* (1946), second plate following p. 17 (labelled Pl. XII).

[30] R. C. Moore, Norman D. Newell, Robert H. Dott, and Joseph L. Borden, "Definition and Classification of the Missouri Subseries of the Pennsylvanian Series in Northeastern Oklahoma," *Guide Book Eleventh Annual Field Conference, Kansas Geol. Society* (1937), p. 43.

[31] Malcolm C. Oakes, "Geology and Mineral Resources of Washington County, Oklahoma," *Oklahoma Geol. Survey Bull. 62* (1940), p. 61.

FIG. 5.—Cross section *CD* showing correlation of beds of upper Missourian age in southern part of Osage County, Oklahoma.

interpretation is correct, the lower part of the sandstone zone may be the time equivalent of the Noxie sandstone of the surface section. Northward from well No. 9 the Chanute sandstones are known to disappear. The manner in which these stratigraphic changes take place in this area has not been studied in sufficient detail to report on them at this time.

Skiatook group.—The Skiatook group comprises those rocks from the base of the Chanute formation to the base of the Seminole formation. It contains the Dewey limestone, the Nellie Bly, Hogshooter, and Coffeyville formations, the Checkerboard limestone, and the Seminole formation. On an outcrop in the NW. $\frac{1}{4}$, Sec. 10, T. 22 N., R. 12 E., Osage County, Oklahoma, the Dewey consists of thin beds of limestone, shaly limestone, and calcareous shales. The same lithologic type continues underground and the zone can easily be recognized in sample work. In the electrical-log cross sections the lithologic character of the Dewey zone produces distinctive normal and lateral resistivity curves which are very useful in correlation work. The Dewey has been traced westward from well No. 33 to well No. 16 beyond which it can not be easily recognized. The Dewey has not been traced by the writer into the Drum limestone which is generally considered its equivalent in Kansas.

The Nellie Bly formation is mostly shale in the area of the cross section. It thins westward from well No. 33 where it is 80 feet thick and is absent at well No. 23. Here the Dewey lies on the Hogshooter formation.

The Hogshooter formation consists of a thin limestone bed which has long been used as a subsurface marker by petroleum geologists in northeastern Oklahoma.

The Coffeyville formation embraces the beds from the base of the Hogshooter formation to the top of the Checkerboard limestone. It contains the Dodds Creek sandstone which is equivalent to the Layton oil sand of the subsurface.

The Checkerboard limestone, constitutes one of the best subsurface markers in northern Oklahoma. In the cross sections it has been traced northward into Kansas and, on the basis of its stratigraphic position and lithologic character, is believed to be correlative with the Hertha limestone. The Hertha limestone is now classified by Moore[32] as the lowest member of the Kansas City group. This correlation is not in accord with the conclusions of Oakes and Jewett[33] who traced the Checkerboard on the surface from Oklahoma into Kansas as they consider it to be correlative with a limestone above the Hepler sandstone in the Pleasanton (formerly Bourbon) group.

Underlying the Checkerboard limestone is the Seminole formation which consists of alternating beds of sandstones, shales, and coals. In this report the Seminole formation is considered to be correlative with the Pleasanton group of

[32] R. C. Moore, personal communication (February 11, 1948).

[33] Malcolm C. Oakes and John M. Jewett, "Upper Desmoinesian and Lower Missourian Rocks in Northeastern Oklahoma and Southeastern Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 5 (1943), pp. 632–40.

Kansas. The Seminole formation contains the Jones and Cleveland sands of the Oklahoma oil fields. The base of the formation, drawn at the base of the sandy beds, marks the lower limit of the Missourian series which rests unconformably on beds of Desmoinesian age.

DESMOINESIAN SERIES

The Desmoinesian series includes the rocks from the unconformity at the base of the Missourian series to the unconformity at the base of the Pennsylvanian. The thickness varies from 200 feet at well No. 1, 435 feet at well No. 19, to 640 feet in well No. 33. These figures indicate a gradual thickening from north to south, but thinning is indicated by wells 13 and 21 which show a thickness of 235 and 340 feet, respectively. This thinning is known to be due to structural conditions.

The Desmoinesian series is subdivided into the Marmaton group and the Cherokee formation.

Marmaton group.—The Marmaton group embraces the rocks from the unconformity at the top of the Desmoinesian to the base of the Fort Scott limestone. Its thickness is relatively uniform, ranging from the minimum of 130 feet at well No. 8, to 240 feet at well No. 33. It is composed of alternating thin shales and thin and massive limestones which can be traced as a zone throughout the cross section. The Marmaton group is not subdivided on the cross section but it is known to contain the Oolagah and Fort Scott limestones. In the subsurface these limestones are referred to as the "Big lime" and the Oswego limestones. Together they form an excellent zone for correlation.

Cherokee formation.—Rocks from the base of the Fort Scott limestone to the base of the Pennsylvanian constitute the Cherokee formation. It is possible that remnants of pre-Cherokee sediments such as the Atokan or Morrowan may be present along the east end of the cross sections, and if so, they have been included in the Cherokee formation. The thickness varies from 30 feet in the wells in Marion County, Kansas, 230 feet at well No. 19, to 410 feet at well No. 33. The Cherokee formation consists of alternating shales, sandstones, and limestones, and, since the Cherokee presents stratigraphic problems which warrant separate study, these beds have not been subdivided in the cross sections. The Cherokee formation is known to thin over structurally high areas as shown in wells 13, 14, 20, and 21. It contains such important and well known subsurface sandstones as the Prue, Skinner, Red Fork, and Bartlesville, and the Verdigris, Pink, and Inola limestones. The stratigraphic position of these subsurface beds is shown at well No. 33. The Cherokee formation rests unconformably on beds of Mississippian age.

MISSISSIPPIAN SYSTEM

Rocks of Mississippian age are known throughout the cross section. Sufficient study has not been made of the Mississippian rocks to classify them properly

with reference to the outcrops. In subsurface work the term "Mississippi" limestone is generally applied to the upper limestone part which, in the cross section, is placed in the Osagian series because all, or nearly all, of the beds are regarded as Osagian in age. If any limestone beds of Meramecian or Kinderhookian, or both, are present in some wells, their identity is unknown to the writer and, for this reason, only the term Osagian is used.

In subsurface work the shale section underlying the limestone zone is known as either Woodford or Chattanooga, and in Kansas the term "Kinderhook" is commonly used. At some places lenses of sandstone, known as the Misener sand, occur at the base of the shale section. This sequence of shales and sandstones which is considered to be Kinderhookian in age, rests unconformably on Silurian-Devonian beds in wells 2 and 3; elsewhere it rests on Ordovician beds.

The thickness of the Mississippian rocks in the area of the cross sections ranges from 415 feet in well No. 1, 430 feet in well No. 19, to 160 feet in well No. 33. Due to the presence of an important regional unconformity at the base of the Pennsylvanian, Mississippian rocks generally show a marked thinning, or they may be absent, over structurally high areas, as indicated at wells 13 and 21 in the cross sections.

SILURIAN-DEVONIAN SYSTEMS

Rocks below Kinderhookian beds in wells 2 and 3 are classified as Silurian-Devonian in age. These rocks, which measure about 40 feet in thickness, rest unconformably on Ordovician beds.

ORDOVICIAN SYSTEM

Rocks of Ordovician age are known throughout the cross section. They are subdivided into the Viola, Simpson, and Arbuckle formations. Only a few wells in the cross section were drilled into the Arbuckle formation which is the oldest formation penetrated.

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VOL. 33, NO. 2 (FEBRUARY, 1949), PP. 153-188, 24 FIGS.

SALINA-GUELPH FIELDS OF SOUTHWESTERN ONTARIO[1]

W. A. ROLIFF[2]
Toronto, Canada

ABSTRACT

The dolomites of the lower part of the Salina formation and the upper part of the Guelph-Lockport formations, Silurian in age, constitute the most important and prolific gas-productive zone in southwestern Ontario, the total production to date amounting to more than 275 billion cubic feet. This zone has also yielded 1,500,000 barrels of oil. Commercial production began in the Salina-Guelph zone in the year 1889, and by 1906 the two most important Salina-Guelph fields in the province had been discovered. Subsequent exploration has been very sporadic, and although eight relatively moderate-sized pools, and several smaller pools have been discovered, 10,000 square miles, or 80 per cent, of the area underlain by these formations remain relatively untested.

Folding and faulting appear to be the dominant factors controlling accumulation, but reefs, variations in porosity and incipient fracturing seem to be almost equally important.

The author describes the geological conditions affecting accumulation and the recently renewed efforts to find additional pools in this zone, and briefly discusses the prospects for future discoveries.

INTRODUCTION

Soon after the publication in 1888 of Professor Edward Orton's report on the "Geology of Ohio," which stated that the gas in Ohio was related to the Cincinnati anticline, Eugene Coste located a well in Lot 7, Concession 1, Gosfield Township, Essex County, Ontario, on the theory that the Cincinnati anticline extended into Ontario. This well was completed on January 23, 1889, at the depth of 1,031 feet, with an initial open flow of 10,000,000 cubic feet per day. This was the first commercial production from the Salina-Guelph zone, of Silurian age, in Ontario, and was followed by the discovery of a small amount of oil on Pelee Island in 1895, the Mersea oil pool in 1902, the Fletcher oil field in 1905, and the Tilbury gas field in 1906. The Fletcher field produced 1,200,000 barrels of oil, and the Tilbury gas field has been the most important gas field in the province. In 1914, the Dawn gas field was discovered; in 1915, the Crumlin pool; in 1929, the D'Clute gas field; in 1935, the Brownsville gas field; in 1936, the Chatham gas field; in 1939, the Malashide gas field; and in 1943, the Zone gas field and the Chatham Gore pool. Since many of the wells in Fletcher field began producing much water with the oil shortly after completion, little attention was given to the oil possibilities of the Salina-Guelph until after the discovery of oil in the Devonian and in the Trenton in Illinois in 1940 and 1941. These latter discoveries raised the question of the possibility of "second crop" oil fields in Ontario in the areas of Devonian production, and this led to a systematic collection and analysis of the information obtained from previous drilling in the province and adjacent states. The results of this study by geologists of Imperial Oil Limited indicated that much new information had been brought to light regarding the occurrence of oil

[1] Read before the Association at Pittsburgh, October 5, 1948. Manuscript received, October 5, 1948. Published by permission of M. L. Haider, director, and general manager of producing department, Imperial Oil Limited, Toronto, Canada.

[2] Senior staff geologist and manager, eastern division, producing department, Imperial Oil Limited.

and gas and the potential oil and gas possibilities of the province. In 1945, this company again undertook active exploration in the province, and since that time has drilled 35 wildcat wells, having the Salina-Guelph as the objective, resulting in the discovery of the West Becher oil and gas pool, the East Becher gas pool, the Kimball gas pool, the Staples oil and gas pool, and the Wheatley gas pool. These are small to moderate-sized pools with drilling depths between 1,000 and 2,000 feet, and appear to be representative of the type of accumulation which may be expected in the Salina-Guelph in Ontario, and perhaps in the adjoining states. The recent minor successes in Ontario, the discovery of oil in the Salina-Guelph zone in the Marine field in Illinois, the finding of commercial gas in the Salina in Livingston County, Michigan, and the numerous large flows of gas encountered in several scattered wells throughout Michigan have created renewed interest in the possibilities of this zone. Since many wells have been drilled to the Salina-Guelph in Ontario, the data obtained from this drilling are of interest to those engaged in, or contemplating exploration of, the possibilities of these formations in Ontario or in the adjoining states.

OUTLINE OF WORK AND ACKNOWLEDGMENTS

Most of the information on conditions in southwestern Ontario was obtained from well records and well samples, although the important outcrops of the Guelph-Lockport and all of the known exposures of the Salina were examined. Approximately 650 exploratory wells have been drilled to the Salina or to the Guelph-Lockport, and some sort of record was available for most of these. Samples were available for about half of the wells, and the writer has examined more than 150 of them. During the years 1934–1937, inclusive, C. S. Evans and J. S. Stewart undertook, for the Geological Survey of Canada, the work of locating as many as possible of the wells drilled to that time, and they obtained their surface elevations. In addition, these geologists re-examined the samples of hundreds of wells and prepared detailed logs of the formations encountered, structure maps, collected statistical data on the production of the various fields, *et cetera*. The results of this work and the data assembled were not published, but were made available to the writer in manuscript form, and have been of inestimable value in this study. Since 1936, J. F. Caley of the Geological Survey of Canada has examined certain parts of the province not covered by Evans and Stewart, and has carried on the work of revision of stratigraphy and examination of the samples from the wells drilled since 1937. The data collected by Caley and the results of his stratigraphic studies were also made available to the writer. The writer has also had the benefit of frequent discussions with Evans, Stewart, and Caley, in regard to the various problems encountered, and their criticisms and suggestions have been most valuable. Acknowledgment is also due J. H. MacLean and H. N. MacDonald, members of the geological staff of Imperial Oil Limited at Chatham, Ontario, who collected many of the data on that company's recent operations.

REGIONAL ASPECTS

Southwestern Ontario lies partly on the rim of the Michigan basin, partly on the extension of the Cincinnati arch, and partly on the rim of the Appalachian basin (Fig. 1).

The region is underlain by strata ranging in age from Cambrian(?) or Lower Ordovician to late Devonian. The areal distribution of these rocks is illustrated in Figure 2. Regionally, the beds dip at low angles, 20–30 feet per mile, toward the south and southwest, away from the pre-Cambrian shield. A broad, ill defined arch crosses southwestern Ontario northeast and southwest from the southwestern tip of the province to Lake Simcoe. The regional structure is interrupted locally by small folds and faults that are, for the most part, discernible only from a detailed study of drilling records. The entire region is covered with a mantle of glacial drift varying from a few feet to more than 500 feet in thickness; and in much of the area the topography of the drift in no way expresses the structure of the underlying bedrock. Rock exposures are few and widely scattered. Faulting, porosity variation, and sedimentary irregularity are evident at some localities. Regional disconformities are known at several horizons, but, wherever these unconformities have been observed, the attitude of the rocks both above and below the breaks is essentially the same. A study of drilling records and of isopach maps indicates that local structure in the Devonian or in the Silurian does not everywhere conform with the structure of the underlying beds.

Figure 3 indicates the sequence and general lithological characteristics of the various formations. Where Paleozoic sediments are thickest, a 4,500-foot well will reach the pre-Cambrian. Limestones and dolomites make up 55½ per cent of the total sediments; shales, 40 per cent; evaporites, 2½ per cent; and sandstones, only 2 per cent. Oil in commercial quantities has been found in four general zones, which, in descending order, are: the Dundee equivalent of Devonian age; the Salina series and Guelph-Lockport formations of Silurian age; and the Trenton-Black River group of Ordovician age. Interesting and important showings have also been encountered in the Medina formation of Silurian age (Whirlpool sandstone member) and in the Basal beds below the Trenton-Black River. Commercial quantities of natural gas have been found in five different formations: the Salina; Guelph-Lockport; Clinton, and Medina formations of Silurian age; and the Trenton-Black River group of Ordovician age. All production excepting that from the Medina occurs in limestones or dolomites. The most important and prolific gas-productive zone occurs in the lower part of the Salina formation, and in the upper part of the Guelph-Lockport formations. This zone has also yielded 1,500,000 barrels of oil, principally from two pools; hence, the possibilities in respect to oil production warrants serious consideration.

Since several pools in Ontario produce from both the Salina and the Guelph-Lockport, this discussion includes the stratigraphical and structural conditions which have influenced oil and gas pooling in both formations.

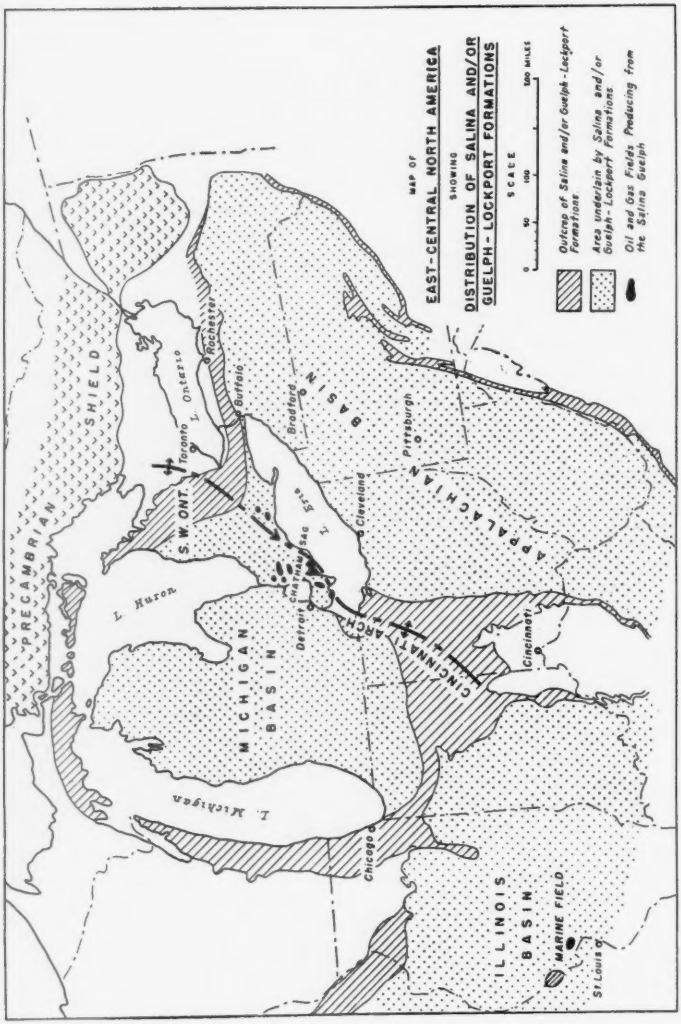

MAP OF
EAST-CENTRAL NORTH AMERICA
SHOWING
DISTRIBUTION OF SALINA AND/OR
GUELPH-LOCKPORT FORMATIONS
SCALE
0 50 100 200 MILES
Outcrop of Salina and/or Guelph-Lockport Formations
Area underlain by Salina and/or Guelph-Lockport Formations
Oil and Gas Fields Producing from the Salina Guelph
PRECAMBRIAN SHIELD
L. Huron
L. Michigan
MICHIGAN BASIN
ILLINOIS BASIN
APPALACHIAN BASIN
CINCINNATI ARCH
S. W. ONT.
Toronto
L. Ontario
Rochester
Buffalo
Bradford
Pittsburgh
Cleveland
Detroit
Chatham
Sarnia
Cincinnati
Chicago
St. Louis
MARINE FIELD

FIG. 1

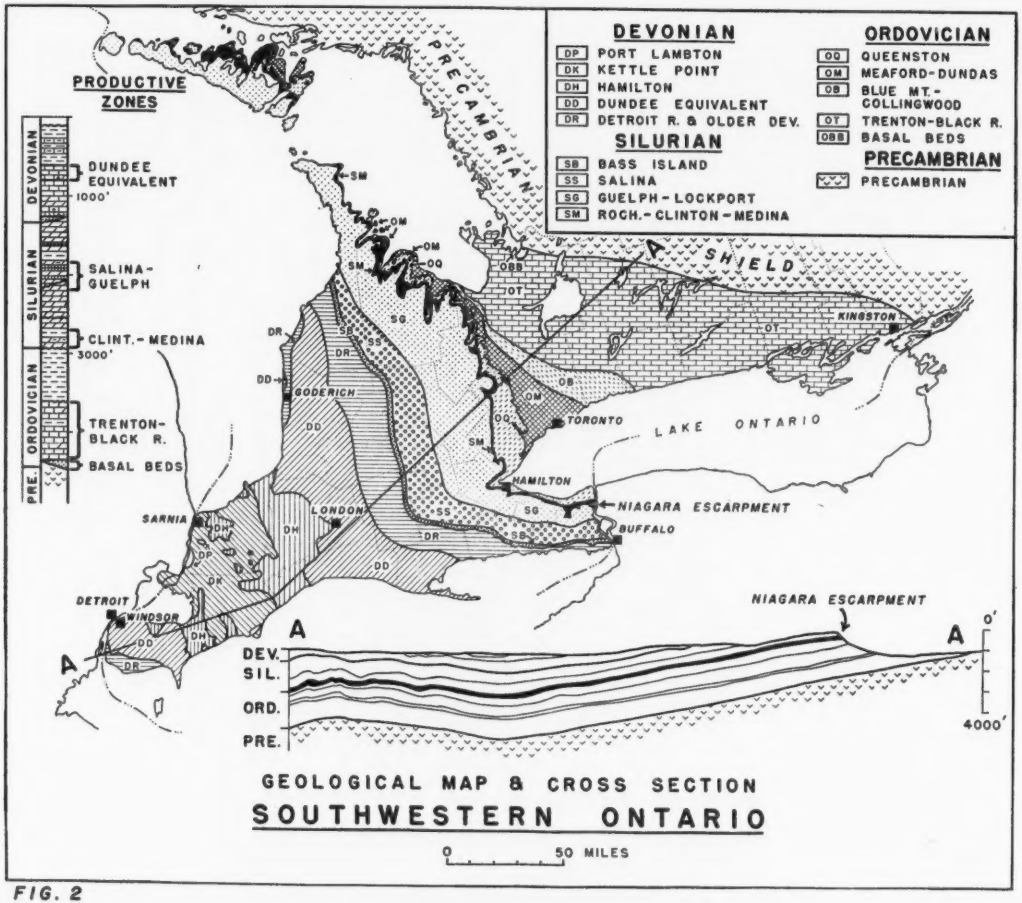

DEVONIAN
DP PORT LAMBTON
DK KETTLE POINT
DH HAMILTON
DD DUNDEE EQUIVALENT
DR DETROIT R. & OLDER DEV.
SILURIAN
SB BASS ISLAND
SS SALINA
SG GUELPH - LOCKPORT
SM ROCH. - CLINTON - MEDINA
ORDOVICIAN
OQ QUEENSTON
OM MEAFORD-DUNDAS
OB BLUE MT. - COLLINGWOOD
OT TRENTON-BLACK R.
OBB BASAL BEDS
PRECAMBRIAN
PRECAMBRIAN
PRODUCTIVE ZONES
DUNDEE EQUIVALENT 1000'
SALINA - GUELPH
CLINT. - MEDINA 3000'
TRENTON - BLACK R.
BASAL BEDS
DEVONIAN
SILURIAN
ORDOVICIAN
PRE.
PRECAMBRIAN
A SHIELD
LAKE ONTARIO
KINGSTON
TORONTO
HAMILTON
NIAGARA ESCARPMENT
BUFFALO
LONDON
SARNIA
GODERICH
DETROIT
WINDSOR
A
A
DEV.
SIL.
ORD.
PRE.
NIAGARA ESCARPMENT
0'
4000'
GEOLOGICAL MAP & CROSS SECTION
SOUTHWESTERN ONTARIO
0 50 MILES

FIG. 2

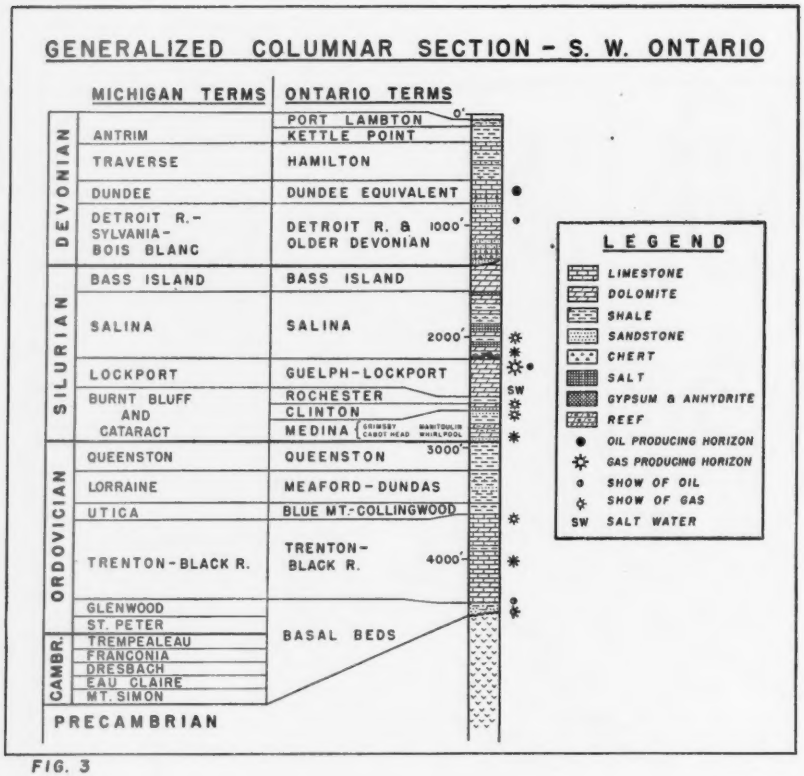


FIG. 3

GUELPH-LOCKPORT FORMATIONS

The Guelph and Lockport formations crop out in southwestern Ontario along and in the proximity of the Niagara escarpment. Where these rocks are exposed it is possible to map these formations separately and Williams[3] gives the following section at the Niagara River, in descending order.

Guelph (undivided)—About 140 feet thick; light grey dolomite generally with a porous saccharoidal texture; some beds are fine-grained and very hard

Lockport

Eramosa beds—12 feet thick; thin even-bedded argillaceous, arenaceous or bituminous dolomites

Undivided—49 feet thick; grey and blue dolomite

Gasport dolomite—7 feet thick; hard grey, sub-crystalline crinoidal limestone

De Cew waterlime—8–9 feet thick; argillaceous, dolomitic limestone

[3] M. Y. Williams, "The Silurian Geology and Faunas of Ontario Peninsula, and Manitoulin and Adjacent Islands," *Geol. Survey of Canada Mem. 111* (1919), pp. 57–62.

According to Caley[4]

> Although the Guelph and Lockport are represented by a great thickness of essentially dolomitic rock, there is what might be called a typical Guelph and a typical Lockport lithology. It is possible, chiefly on a basis of physical characters, among which rock texture holds a prominent place, to assign hand specimens of the two typical phases to their respective formations with reasonable assurance. However, there is considerable vertical range, including the upper part of the Lockport, and the lower part of the Guelph, where the lithology and physical characters are so similar that it would be impossible to place hand specimens from this range into their respective formations. The two formations have been separated chiefly on faunal evidence, the typical Guelph enclosing a profusion of large pelecypods and gasteropods; many of these are not confined to the Guelph, but they are characteristic of certain horizons in these rocks. As examined in hand specimen and at the outcrop, the typical Guelph rocks are commonly more or less granular and have a glistening lustre or fresh surface; the typical Lockport is commonly lighter in colour and more coarsely crystalline.

Massive reef structures have been observed in the exposed sections of both the Lockport and the Guelph, and in several areas, subsurface information indicates the presence of reefs.

The examination of a great many well samples throughout the province, however, has failed to yield any satisfactory criteria for the separation of these two formations in well samples, and they have been logged as a single lithological unit under the term Guelph-Lockport. In general, in well samples, the Guelph-Lockport consists of medium- to coarse-textured, buff, gray, bluish gray, and nearly white crystalline to granular dolomites, commonly saccharoidal in texture in the upper part. The lower part is commonly light gray to nearly white, and in places, the lower middle part is cherty.

The Guelph-Lockport varies in thickness from 75 feet in the vicinity of Sarnia, to more than 500 feet southeast of Windsor (Fig. 4), and in places shows as much as 100 feet difference in thickness in a few miles distance. The known reef areas, determined on the basis of subsurface information, occur in, or bordering, the belts of rapid change in thickness.

Oil or gas, or both, are produced from the Guelph-Lockport, from several zones in the upper 120 feet of the formation, and all pools are situated in the vicinity of relatively rapid change in thickness of the formation (Fig. 4).

SALINA FORMATION

The Salina formation lies between the Guelph-Lockport dolomites below, and the Bass Island series above, and consists of thin-bedded, fine-grained, gray, buff, and brown dolomites and limestones, shaly dolomites and limestones, dolomitic and calcareous shales, beds of gypsum and anhydrite, and in many places, beds of salt. There is practically no pure shale in the entire succession, and the dolomitic shale may, perhaps, be more accurately defined as an argillo-calcareous

[4] J. F. Caley, "Paleaozoic Geology of the Brantford Area, Ontario," *Geol. Survey of Canada Mem. 226* (1941), p. 27.

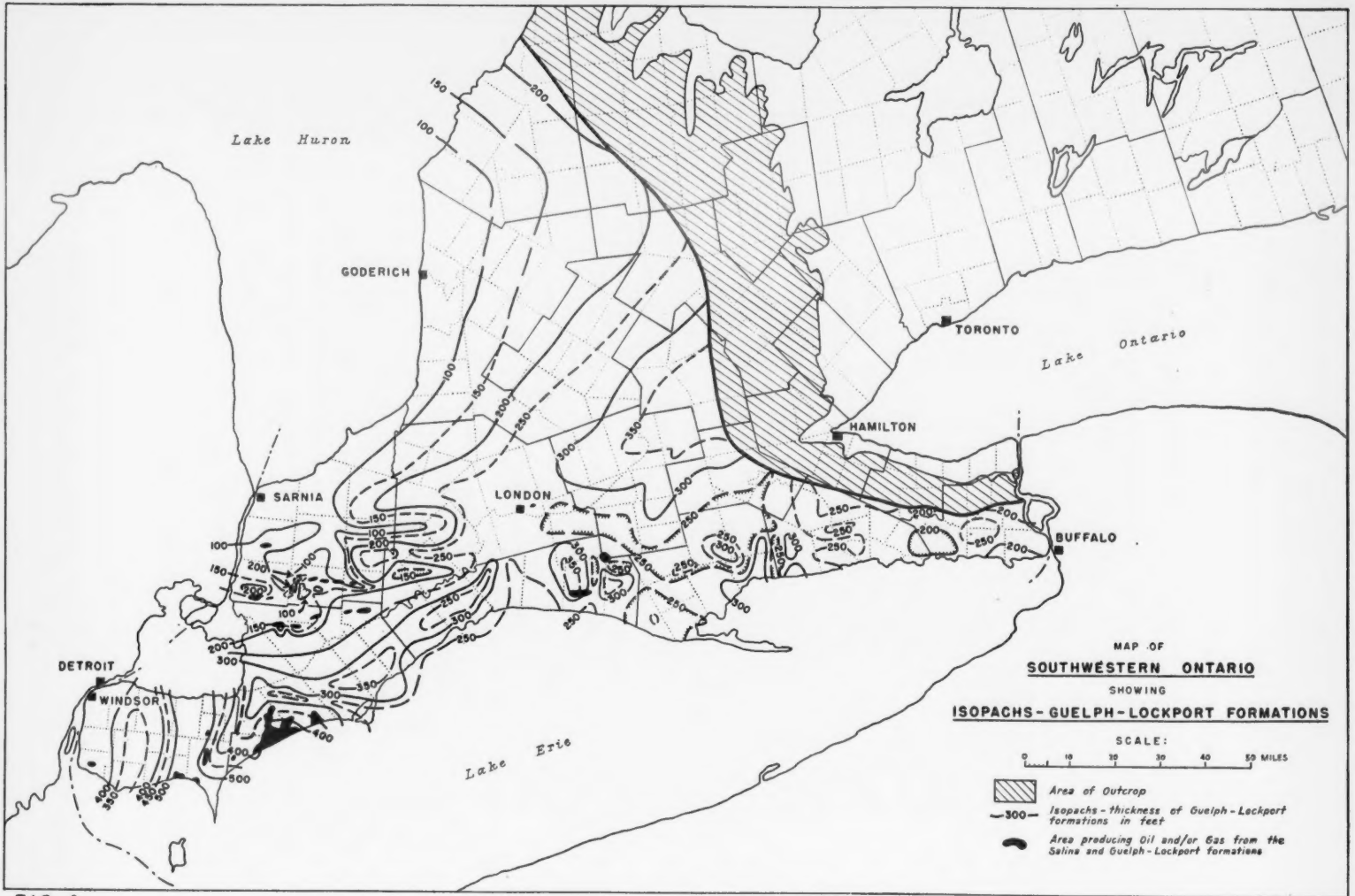

Lake Huron
GODERICH
SARNIA
LONDON
TORONTO
Lake Ontario
HAMILTON
BUFFALO
DETROIT
WINDSOR
Lake Erie
MAP OF
SOUTHWESTERN ONTARIO
SHOWING
ISOPACHS - GUELPH - LOCKPORT FORMATIONS
SCALE:
0 10 20 30 40 50 MILES
Area of Outcrop
300 Isopachs - thickness of Guelph - Lockport formations in feet
Area producing Oil and/or Gas from the Salina and Guelph - Lockport formations

FIG. 4

mud rock, the nearest approach to true shale being some thin zones of gray and greenish gray and reddish argillaceous rock in some wells in the southwestern part of the province, and in wells and outcrops in the Walkerton-Kincardine area. In general, the succession consists of alternating gray dolomitic shale or argillo-calcareous mud rock, and intervals of brown-colored fine-grained to dense dolomite, rarely with dark bituminous streaks, and commonly with thick beds of salt, particularly in the area west of London. Small quantities of white anhydrite and gypsum are present throughout practically the entire formation, although perhaps more prevalent in the gray shaly intervals. No fossils have been found in outcrop, but a few ostracods have been observed in cores and well cuttings of the succession. An horizon characterized by the presence of well rounded and frosted sand grains seems to have fairly wide distribution in the area west of London.

It is difficult to fix definite and sharp demarcation between the Salina and the Guelph-Lockport below. In general, the base of the Salina is placed where there is a marked increase in size of grain to sugary-textured dolomites, from the dense shaly dolomites that lie below the lowest anhydrite bed of the Salina. Its relation to the Guelph-Lockport in general appears to be conformable, but locally at least, there is definite evidence of erosion at the end of Guelph-Lockport time. The top boundary of the Salina is placed just above the highest shaly dolomite containing anhydrite or gypsum. This boundary is fairly satisfactory from Essex County east into Norfolk County. Farther east in Haldimand and Welland counties, where the Akron-Bertie formations (regarded as equivalent to the Bass Island) crop out, these latter contain shaly strata near the base, and this similarity between basal Bass Island or Akron-Bertie beds and the uppermost Salina, makes the contact uncertain in the samples of many wells in this area. The Salina formation varies in thickness from 300 to more than 1,350 feet (Fig. 5), with the aggregate thickness of the salt beds ranging from absence to more than 650 feet.

In Michigan, according to Landes,[5] detailed studies of well samples led to the discovery that the Salina rocks could be subdivided into traceable units which he designated A to G. Lithologically, these units may be briefly described as follows (descending order).

Unit

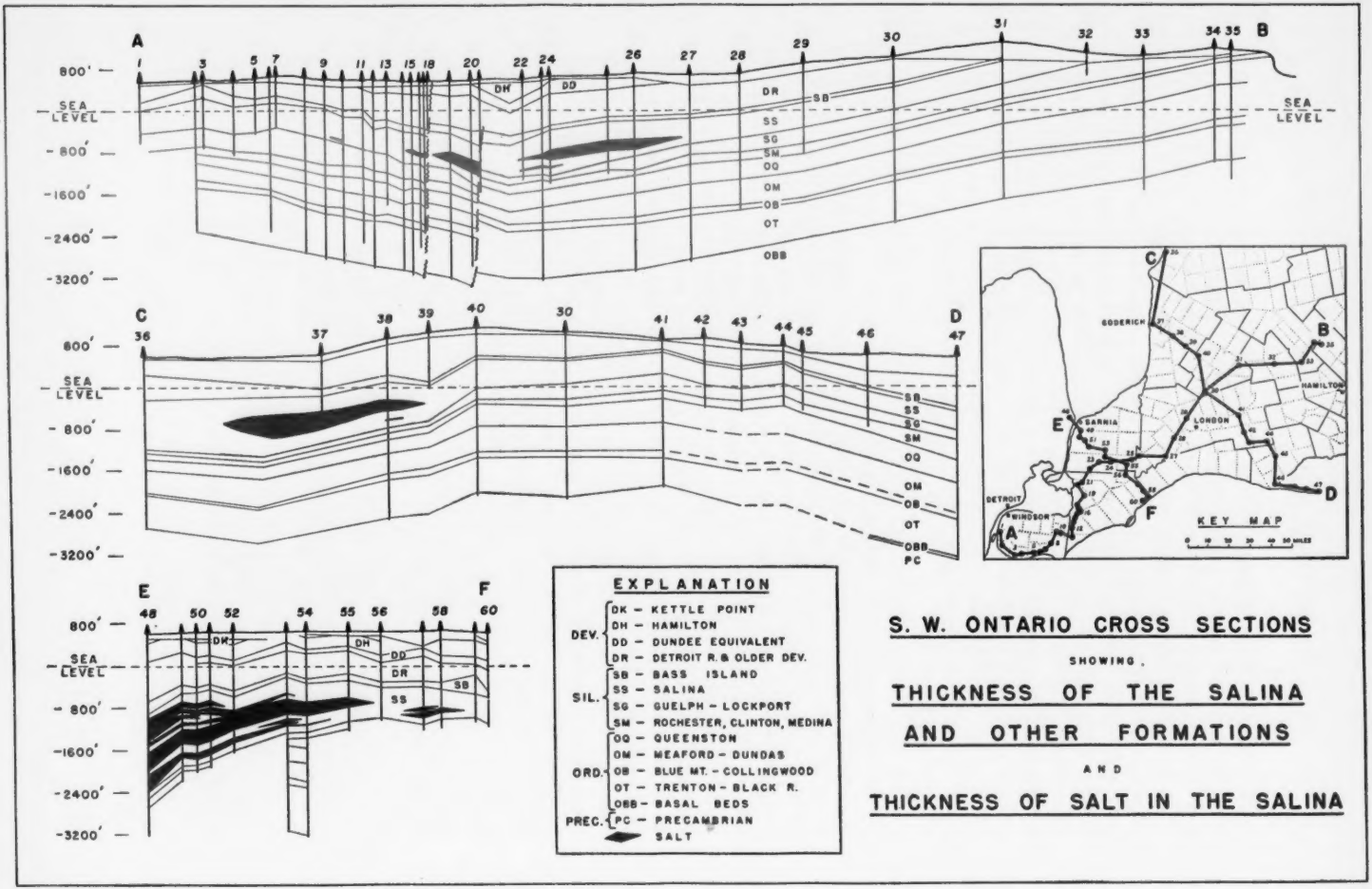
G—Uppermost unit in Salina. Shaly dolomite with some brown dolomite and green and red shales in northern Michigan

F—Dominantly salt in thick beds separated by beds of varying thickness of gray, green, and red shale, shaly dolomite, gray to buff and brown dolomite. Anhydrite is almost everywhere present

The foregoing units of Landes can be traced across southwestern Ontario (Figs. 6 and 7), and these units in Ontario are in general very similar lithologically, to the corresponding units in Michigan. Not all units are present at any particular

[5] Kenneth K. Landes, "The Salina and Bass Island Rocks in the Michigan Basin," *U. S. Geol. Survey Prelim. Map 40*, Oil and Gas Invest. Ser. (1945).

FIG. 4



S. W. ONTARIO CROSS SECTIONS

SHOWING

THICKNESS OF THE SALINA AND OTHER FORMATIONS

AND

THICKNESS OF SALT IN THE SALINA

FIG 5

LIST OF WELLS SHOWN IN FIGURE 5

Number on Cross Section	*Well*	*Township*	*County*
1	Brunner Mond	Anderdon	Essex
2	Bush 1	Malden	Essex
3	J. Bondy	Colchester S.	Essex
4	Milner Farm	Colchester S.	Essex
5	Coste 2	Gosfield S.	Essex
6	Ferris 15	Gosfield S.	Essex
7	Ruthven	Gosfield S.	Essex
8	Imperial Oil	Mersea	Essex
9	Rosslyn	Tilbury W.	Essex
10	Union-Imperial 3	Tilbury W.	Essex
11	Coste 2	Romney	Kent
12	Coste 6	Tilbury E.	Kent
13	J. Burgess 1	Tilbury E.	Kent
14	Union 18	Tilbury E.	Kent
15	Union 6	Tilbury E.	Kent
16	Rowe Bruette 1	Raleigh	Kent
17	Imperial-Rhodes 1	Raleigh	Kent
18	Imperial-Tape 1	Raleigh	Kent
19	Coste 7	Dover E.	Kent
20	Union-Imperial-Electric 1	Dover E.	Kent
21	Union-Imperial 1	Chatham	Kent
22	Imperial-Pardee 1	Sombra	Lambton
23	Union Dawn 2	Dawn	Lambton
24	Union Dawn 56	Dawn	Lambton
25	Union Dawn 54	Euphemia	Lambton
26	Southern Ontario Gas 1	Mosa	Middlesex
27	Union 1	Ekfrid	Middlesex
28	Caradoc 20	Ekfrid	Middlesex
29	Ilderton Well	London	Middlesex
30	St. Mary's Cement Works	Blanshard	Perth
31	Volcanic 1	N. Easthope	Perth
32	Kitchener Well	Waterloo	Waterloo
33	Bollert Oil and Gas Co. I	Puslinch	Wellington
34	Rockwood Oil and Gas	Eramosa	Wellington
35	Suburban Gas 1	Nassagawaga	Halton
36	McRae Pt.	Kincardine	Bruce
37	Western Canada Flour	Goderich	Huron
38	H. Trewartha 1	Hullet	Huron
39	Seaforth Well	McKillop	Huron
40	Mitchell Synd. 1	Logan	Perth
41	Beachville Well	Oxford N.	Oxford
42	Lot 12, Con. 4	Deerham	Oxford
43	Ajax 1	Deerham	Oxford
44	Imperial O'brien 1	S. Norwich	Oxford
45	J. A. Reid 1	Charlotteville	Norfolk
46	Port Rowan	S. Walsingham	Norfolk
47	Dom. Natural Gas 1	S. Walsingham	Norfolk
48	Mueller Brass Co.	Port Huron	Michigan
49	Lucas Well	Sarnia	Lambton
50	Imperial Corunna 1	Moore	Lambton
51	Imperial Corunna 2	Moore	Lambton
52	Brigden	Moore	Lambton
53	Oil Springs	Enniskillen	Lambton
54	Coste 4	Dawn	Lambton
55	Annette 16	Euphemia	Lambton
56	Union Zone 23	Zone	Kent
57	Imperial Clachan 1	Orford	Kent
58	Imperial Henry 1	Orford	Kent
59	Olga	Orford	Kent
60	Imperial Carnegie 1	Orford	Kent

Unit

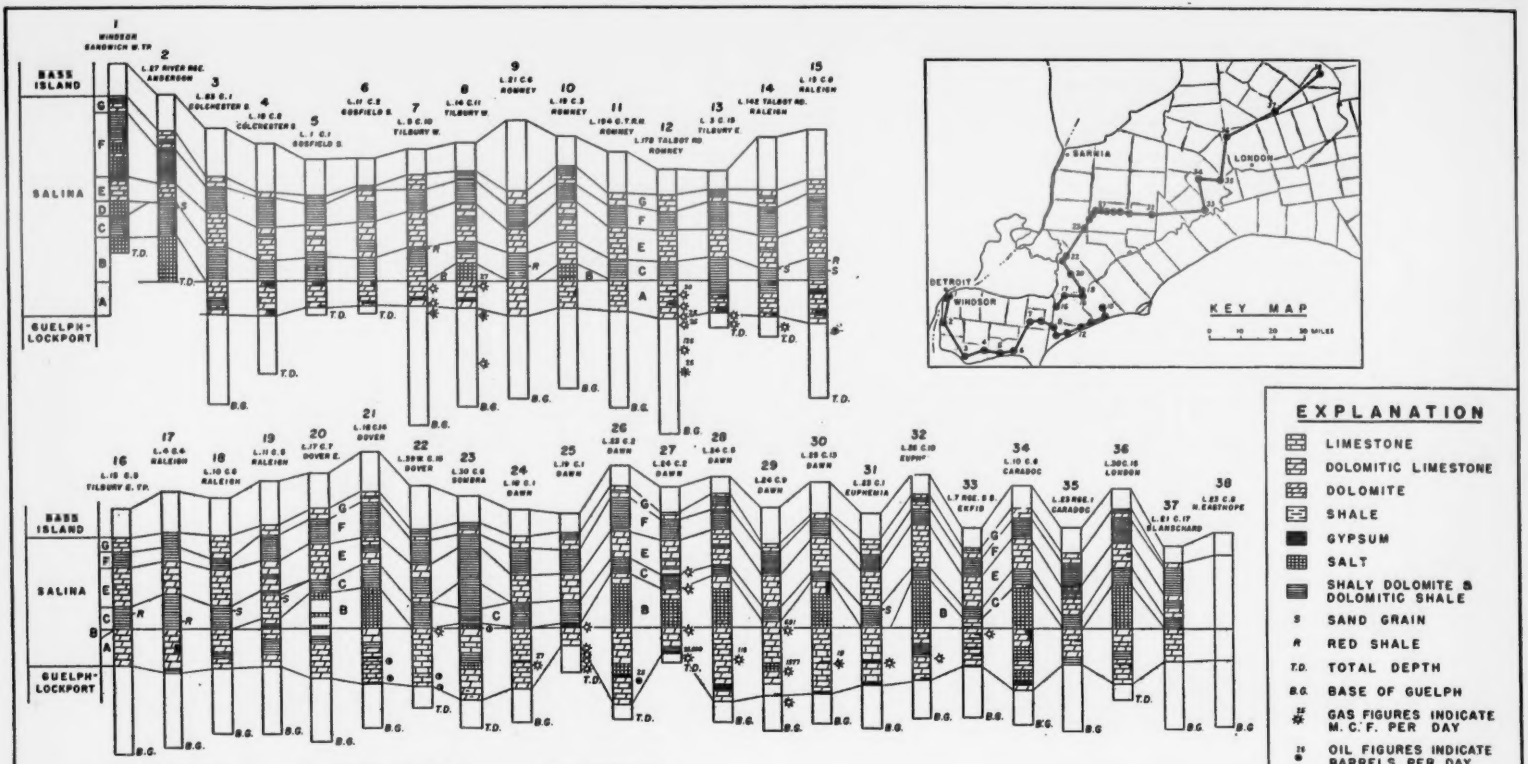
E—Relatively thin shaly unit

D—Nearly pure salt. In places contains thin partings of buff dolomite

B—Thick salt bed with thin layers of dolomite

A—Basal unit of Salina, consists of mainly brown dolomites with subordinate limestone and anhydrite, divided, in some areas by one or two thick salt beds. Gray shaly dolomite present in some places

FIG 5

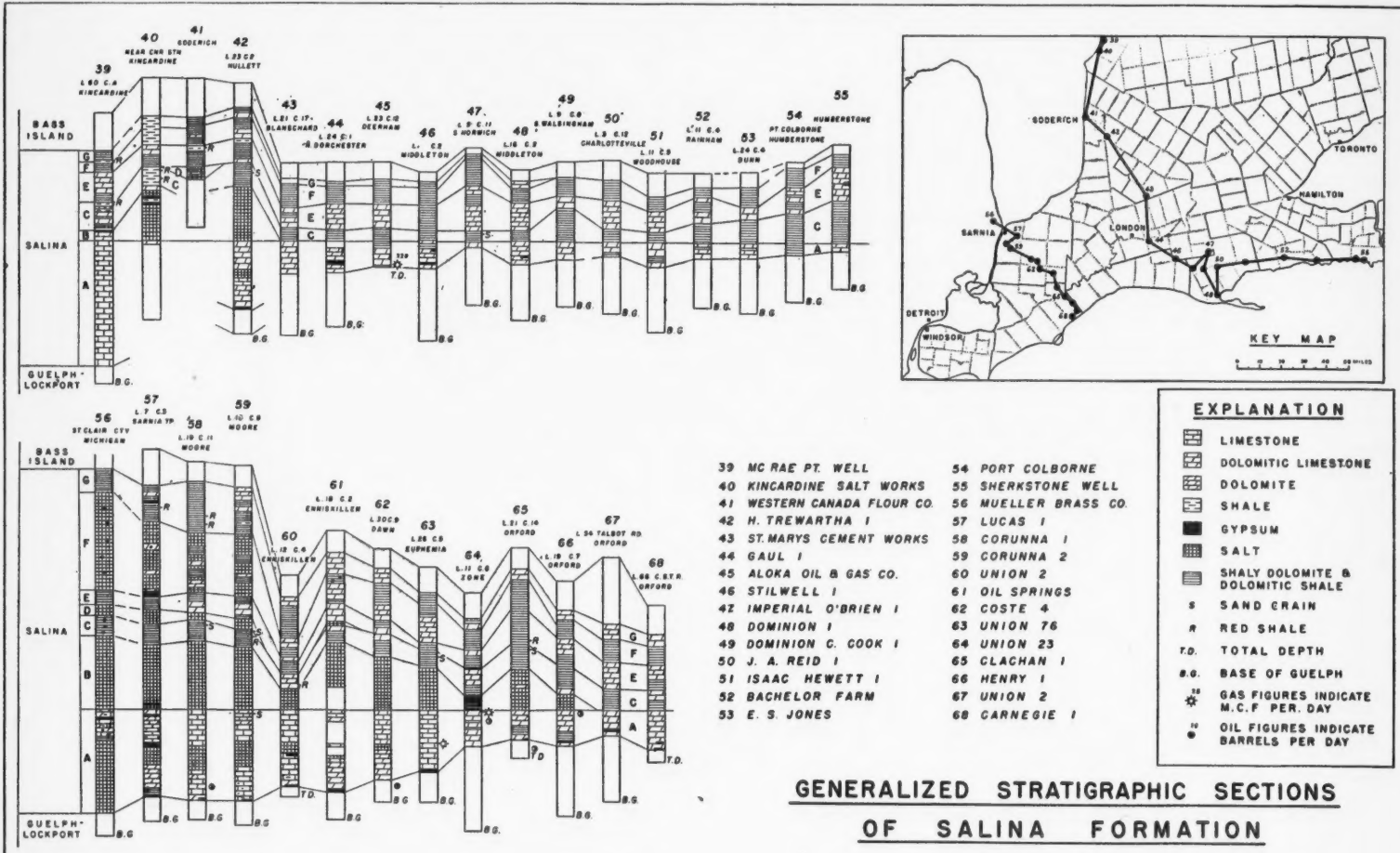


1 WINDSOR SALT CO.
2 BRUNNER MUND 6
3 J. BONDY
4 MILNER FARM
5 KINGSVILLE (COSTE 2)
6 RUTHVEN WELL
7 ROSLYN 1
8 UNION IMPERIAL 3
9 COSTE 2
10 COSTE 3
11 ERIE PETROLEUMS
12 UNION 251
13 R. DAWSON 2
14 UNION D'CLUTE 14
15 UNION D'CLUTE 8
16 R. J. BURGESS
17 UNION 18
18 RHODES 1
19 TAPE 1
20 COSTE 7
21 UNION IMP. ELECTRIC 3
22 UNION IMP. ELECTRIC 2
23 IMPERIAL PARDEE 1
24 UNION DAWN 46
25 UNION DAWN 47
26 UNION 61
27 UNION 59
28 UNION 42
29 UNION 67
30 UNION 72
31 UNION 26
32 UNION 54
33 UNION 1
34 UNION 2
35 LONGWOOD WELL
36 DENFIELD WELL
37 ST. MARY'S CEMENT WORKS
38 VOLCANIC NO.1

GENERALIZED STRATIGRAPHIC SECTIONS OF SALINA FORMATION

FIG. 6

FIG. 6


BASS ISLAND
SALINA
GUELPH-LOCKPORT
B.G.
T.D.
39 L 60 C.A KINCARDINE
40 NEAR CNR STN KINCARDINE
41 GODERICH
42 L 23 C 2 HULLETT
43 L 21 C 17 BLANSCHARD
44 L 24 C 1 A DORCHESTER
45 L 33 C 12 DEERHAM
46 L C 2 MIDDLETON
47 L 9 C 11 S NORWICH
48 L 16 C 2 MIDDLETON
49 L 9 C 6 S WALSINGHAM
50 L 3 C 12 CHARLOTTEVILLE
51 L 11 C 5 WOODHOUSE
52 L 11 C 4 RAINHAM
53 L 24 C 4 DUNN
54 PT COLBORNE HUMBERSTONE
55 HUMBERSTONE
56 ST CLAIR CTY MICHIGAN
57 L 7 C 3 SARNIA TP
58 L 19 C 11 MOORE
59 L 40 C 9 MOORE
60 L 13 C 6 ENNISKILLEN
61 L 18 C 2 ENNISKILLEN
62 L 30 C 9 DAWN
63 L 26 C 5 EUPHEMIA
64 L 11 C 6 ZONE
65 L 21 C 16 ORFORD
66 L 18 C 7 ORFORD
67 L 34 TALBOT RD ORFORD
68 L 66 C ST R ORFORD
GODERICH
TORONTO
HAMILTON
LONDON
SARNIA
DETROIT
WINDSOR
KEY MAP

39 MC RAE PT. WELL	54 PORT COLBORNE
40 KINCARDINE SALT WORKS	55 SHERKSTONE WELL
41 WESTERN CANADA FLOUR CO.	56 MUELLER BRASS CO.
42 H. TREWARTHA 1	57 LUCAS 1
43 ST. MARYS CEMENT WORKS	58 CORUNNA 1
44 GAUL 1	59 CORUNNA 2
45 ALOKA OIL & GAS CO.	60 UNION 2
46 STILWELL 1	61 OIL SPRINGS
47 IMPERIAL O'BRIEN 1	62 COSTE 4
48 DOMINION 1	63 UNION 76
49 DOMINION C. COOK 1	64 UNION 23
50 J. A. REID 1	65 CLACHAN 1
51 ISAAC HEWETT 1	66 HENRY 1
52 BACHELOR FARM	67 UNION 2
53 E. S. JONES	68 CARNEGIE 1

EXPLANATION

- LIMESTONE
- DOLOMITIC LIMESTONE
- DOLOMITE
- SHALE
- GYPSUM
- SALT
- SHALY DOLOMITE & DOLOMITIC SHALE
- S SAND GRAIN
- R RED SHALE
- T.D. TOTAL DEPTH
- B.G. BASE OF GUELPH
- GAS FIGURES INDICATE M.C.F PER. DAY
- OIL FIGURES INDICATE BARRELS PER DAY

GENERALIZED STRATIGRAPHIC SECTIONS OF SALINA FORMATION

VERTICAL SCALE

0 200 400 600 800 1000 FEET

FIG. 7

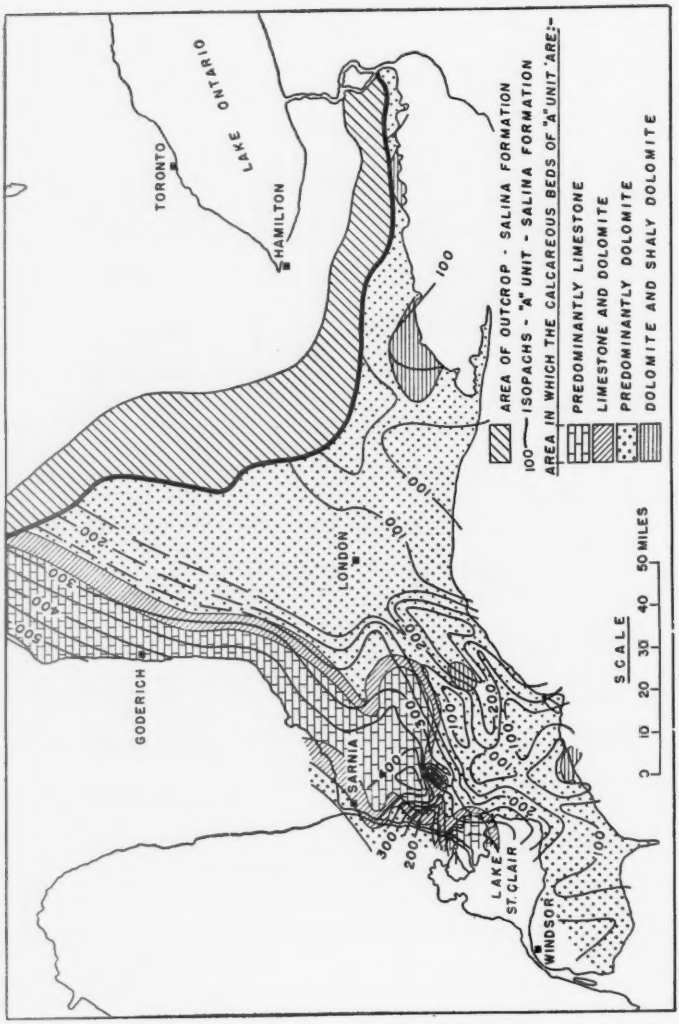

TORONTO
LAKE ONTARIO
HAMILTON
LONDON
GODERICH
SARNIA
LAKE ST. CLAIR
WINDSOR
AREA OF OUTCROP - SALINA FORMATION
100 ISOPACHS - "A" UNIT - SALINA FORMATION
AREA IN WHICH THE CALCAREOUS BEDS OF "A" UNIT ARE:-
PREDOMINANTLY LIMESTONE
LIMESTONE AND DOLOMITE
PREDOMINANTLY DOLOMITE
DOLOMITE AND SHALY DOLOMITE
SCALE
0 10 20 30 40 50 MILES

FIG. 8

locality, and any unit may show local lithologic variations. All salt units appear to pinch out eastward, but in a few places may change laterally into dolomites or argillo-calcareous rocks. Unit A yields oil and gas in southwestern Ontario, and is therefore considered in more detail.

With the possible exception of a few wells in the Dawn oil and gas field, Unit A is present in all wells west of the outcrop belt that reach sufficient depth to encounter it. It ranges in thickness from 50 feet to 450 feet (Fig. 8), and is composed of calcareous or argillo-calcareous rocks with a middle salt member in the area east and south of Lake Huron (Figs. 6 and 7). In much of this latter area, these calcareous rocks are predominantly limestones (Fig. 8) that grade laterally outwardly into a belt composed of limestones and dolomites, thence into dolomites, and finally into dolomites and shaly dolomites. Unit A is overlain in the western part of the province by the thick Unit B salt, and in the eastern part by the argillo-calcareous beds.

Commercial quantities of gas have been found in the upper part of Unit A, where this is composed of dolomites or dolomites and limestones, and this has been designated the "upper pay" of the lower Salina. Oil saturation and showings of oil have been observed in it. Commercial gas and oil have also been obtained from the part underlying the Unit A salt member, or its equivalent, where dolomites or dolomites and limestones are present in this underlying part. This part has been designated the "lower pay" of the lower Salina. All important Salina production occurs in or near the belt composed of limestones and dolomites. So far, no oil or gas has been produced in the area where the calcareous beds of Unit A are dominantly limestone, and only relatively small volumes of gas are obtained in the area in which the calcareous beds of Unit A are predominantly dolomite.

STRUCTURE

Guelph-Lockport sedimentation appears to have been initiated on a sea-floor with relatively little relief (Fig. 9) that later subsided to form a deep trough extending northeast and southwest through the present site of the city of London (Fig. 4). These rocks overlie the Rochester formation in the extreme south part of the province and the Clinton and Cabot Head, successively older formations, toward the north (Fig. 9), all of which are relatively thin. Differential movements probably commenced early in Guelph-Lockport time and by early Salina time the present-day structure had commenced to take form (Figs. 6 and 7.) By the close of the Salina, this form was considerably accelerated, the differential from London to Sarnia having increased to more than 800 feet (Fig. 10). Present structural relief on the base of the Guelph-Lockport from London to Sarnia is approximately 1,700 feet. That the area, during deposition of the Guelph-Lockport and the Salina, was frequently subject to oscillating movements, is evidenced by the varying thickness of the Guelph-Lockport (Fig. 4) and the several recognizable units of the Salina (Figs. 6 and 7). These movements were accompanied by fault-

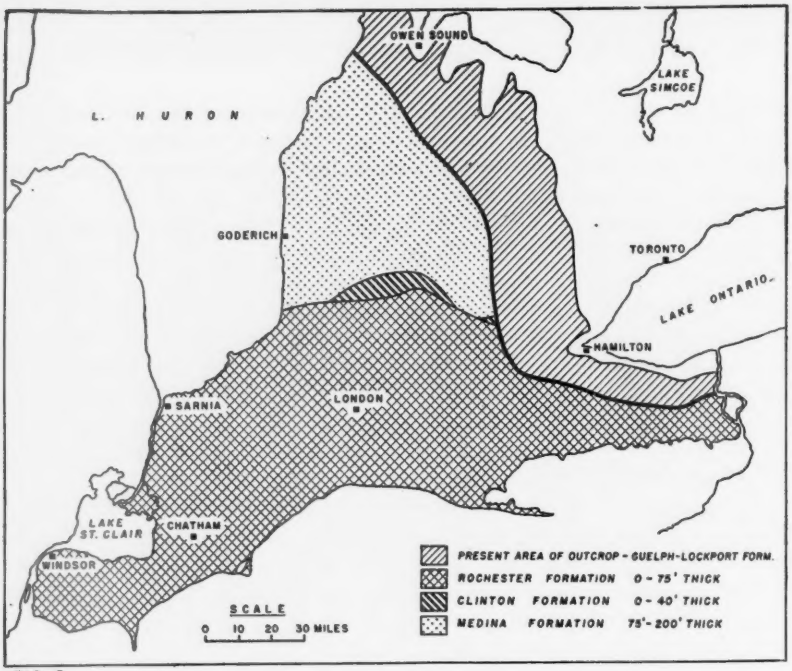

OWEN SOUND
LAKE SIMCOE
L. HURON
GODERICH
TORONTO
LAKE ONTARIO
HAMILTON
SARNIA
LONDON
LAKE ST. CLAIR
CHATHAM
WINDSOR
SCALE
0 10 20 30 MILES
PRESENT AREA OF OUTCROP - GUELPH-LOCKPORT FORM.
ROCHESTER FORMATION 0 - 75' THICK
CLINTON FORMATION 0 - 40' THICK
MEDINA FORMATION 75' - 200' THICK

FIG. 9

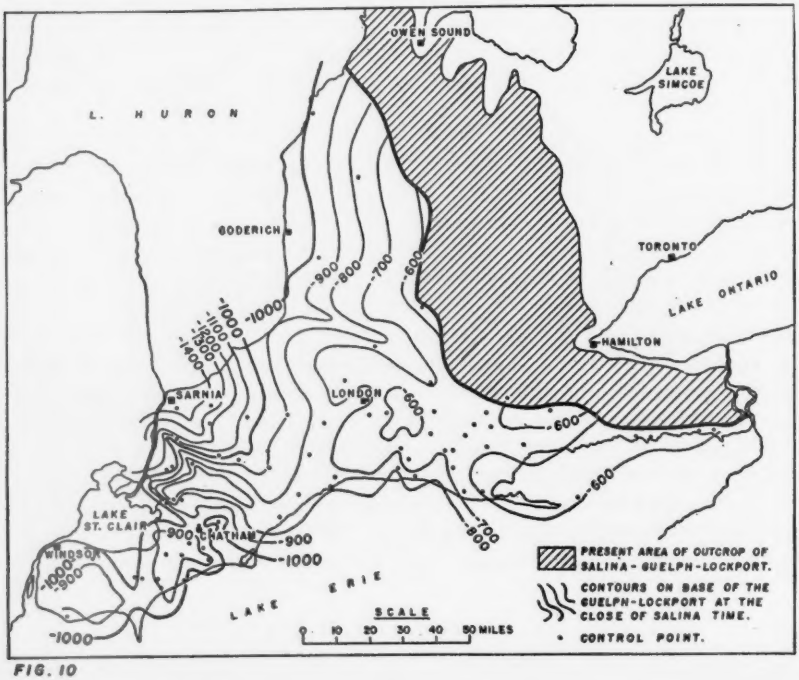

OWEN SOUND
LAKE SIMCOE
L. HURON
GODERICH
TORONTO
LAKE ONTARIO
HAMILTON
SARNIA
LONDON
LAKE ST. CLAIR
CHATHAM
WINDSOR
LAKE ERIE
-1000
-1100
-1200
-1300
-1400
-900
-800
-700
-600
SCALE
0 10 20 30 40 50 MILES
PRESENT AREA OF OUTCROP OF SALINA - GUELPH-LOCKPORT.
CONTOURS ON BASE OF THE GUELPH-LOCKPORT AT THE CLOSE OF SALINA TIME.
CONTROL POINT.

FIG. 10

ing which, on the north of Chatham, seems to have followed general east-west to northwest trends, and on the south of Chatham general north-south trends. These faults have displacements ranging from 50 feet or less to more than 250 feet, and the east-west trending faults generally have the downthrown side on the south. Movements of relative importance seem to have occurred during Salina, Bass Island, and Detroit River time. Several faults show no evidence of

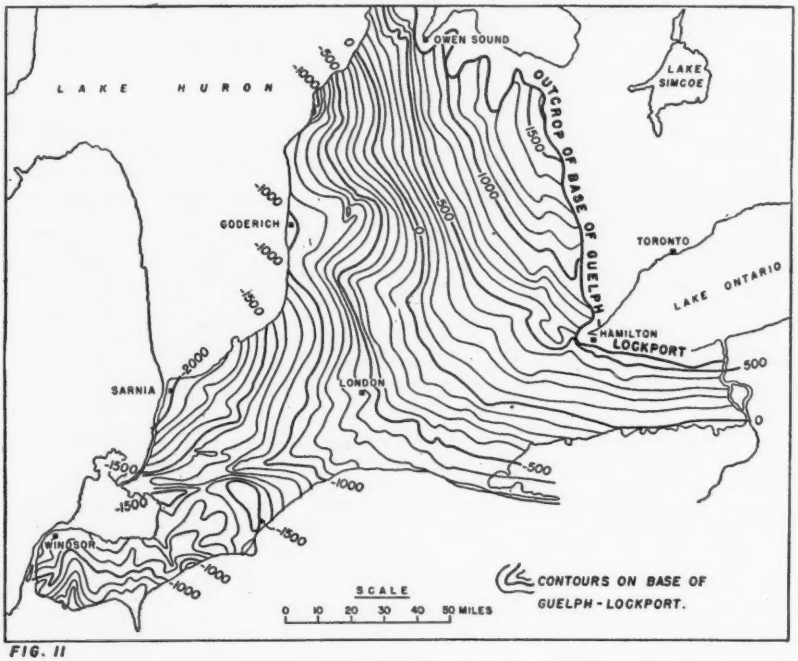


FIG. 11

movement after the close of Detroit River sedimentation, while one fault-plane is known that cuts the youngest Devonian sediments, the Port Lambton beds.

Due to the occurrence of reefs at the top of the Guelph-Lockport, present general structural configuration of the Salina-Guelph-Lockport group is perhaps best illustrated by the contours drawn on the base of the Guelph-Lockport (Fig. 11). These show the presence of a definite, but ill defined arch trending northeast and southwest, through the city of London. Superimposed on this broad feature are several more sharply defined local folds and faults of varying degrees of magnitude and closure and complexity. These local features are discussed in more detail in the description of the oil and gas pools which follows.

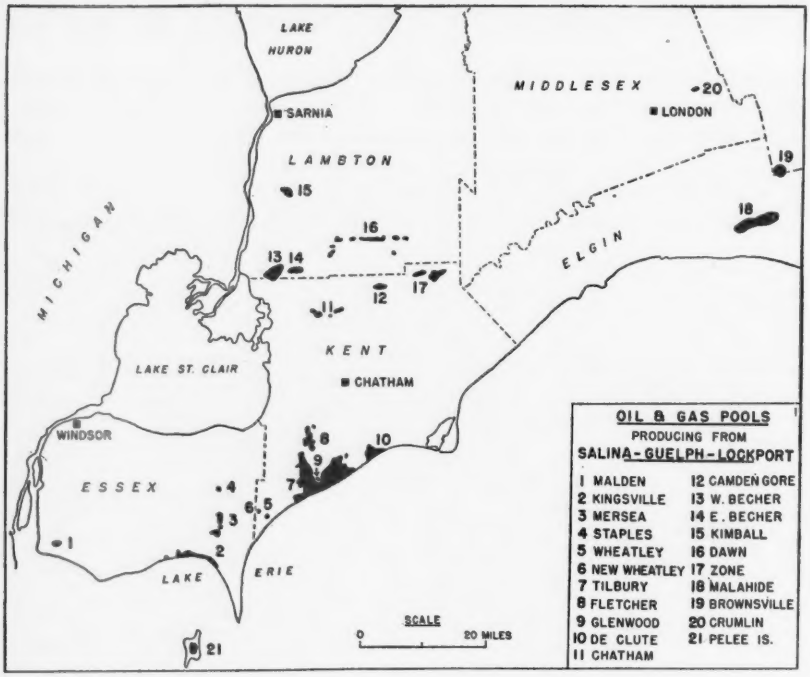


FIG. 12

OIL AND GAS POOLS IN GUELPH-LOCKPORT AND SALINA (FIG. 12)

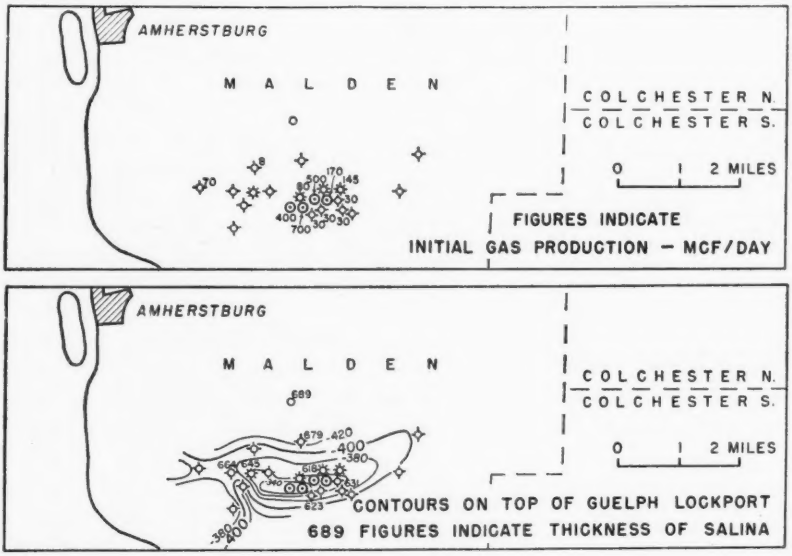
Number on Map	*Field or Pool*	*County*	*Year of Discovery*	*Estimated Ultimate Production of Pool*	*Number of Wells Completed to July 1, 1948*	*Producing Formation*
2	Kingsville	Essex	1888	80,000,000 Mcf.	85	Guelph
21	Pelee Island	Essex	1895	5,000 bbls.	29	Salina
3	Mersea	Essex	1902	235,175 bbls.*	60	Guelph
5	Wheatley	Kent	1903	9,100 bbls.	4	Guelph
8	Fletcher and	Kent	1905	1,200,000 bbls.	160?	Salina? and Guelph
9	Glenwood					
7	Tilbury	Kent	1906	250,000,000 Mcf.	400	Salina and Guelph
16	Dawn	Lambton	1914	55,000 bbls.	7	Salina and Guelph
				20,000,000 Mcf.	83	
20	Crumlin	Middlesex	1915	15,405 Mcf.	3	Guelph
10	D'Clute	Kent	1929	15,000,000 Mcf.	60	Salina and Guelph
19	Brownsville	Oxford	1935	3,500,000 Mcf.	90	Guelph
11	Chatham	Kent	1936	3,800,000 Mcf.	70	Salina and Guelph
18	Malahide	Elgin	1939	4,000,000 Mcf.	100	Guelph
17	Zone	Kent	1943	9,000,000 Mcf.	60	Salina and Guelph
12	Camden Gore	Kent	1943	700,000 Mcf.	26	Salina
1	Malden	Essex	1946	200,000 Mcf.	15	Guelph
14	East Becher	Lambton	1946	600,000 Mcf.	8	Guelph
13	West Becher	Lambton	1946	3,000,000 Mcf.	22	Salina
				400,000 bbls.	12	
15	Kimball	Lambton	1947	3,000,000 Mcf.	13	Salina
4	Staples	Essex	1948	200,000 Mcf.	2	Guelph
				50,000 bbls.	2	
6	New Wheatley	Kent	1948	200,000 Mcf.	1	Guelph

* This production is from 21 wells.

Separate records have not been kept of the amount of production obtained from the Salina.

GEOLOGICAL CONDITIONS OF ACCUMULATION BY POOLS

Malden pool.—Fifteen wells have been drilled in this pool to depths of approximately 1,000 feet. Gas has been produced from the Salina and the Guelph, the initials ranging from 30 Mcf. to 700 Mcf.[6] a day. Only five wells had initials of more than 100 Mcf. a day. Most of the production from the Salina has been less than 100 Mcf. a day, whereas the larger wells produced from the Guelph (Fig. 13).



☼ GAS WELL-PROD. FROM SALINA ⊙ GAS WELL-PROD. FROM GUELPH
FIG. 13 ✧ DRY HOLE

Contours on top of the Guelph (Fig. 13) suggest an elongate dome or anticline, and the Guelph is highest at the point of largest production. The Salina is thinnest over the high Guelph (Fig. 13), suggesting pre-Salina folding or reef conditions. Because of the nature of the production, the writer believes that the gas in this pool is obtained from a small reef in the Guelph.

Kingsville field.—Approximately 85 wells have been drilled in this field from 900 to 1,100 feet in depth, and gas was produced from the upper part of the Guelph-Lockport. Many wells had initial capacities of several million cubic feet

[6] Mcf.—1,000 cubic feet.

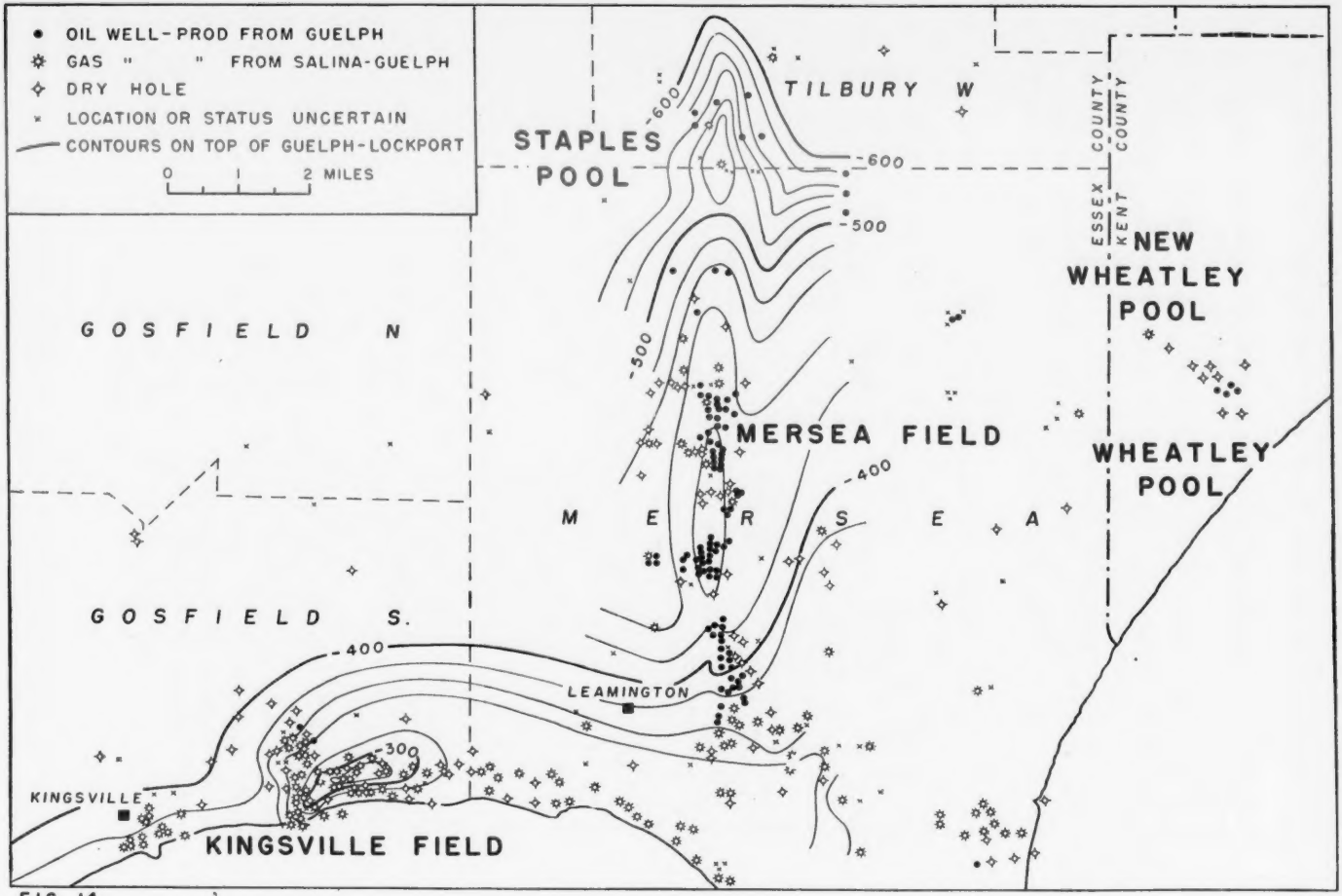

OIL WELL - PROD FROM GUELPH
GAS " " FROM SALINA-GUELPH
DRY HOLE
LOCATION OR STATUS UNCERTAIN
CONTOURS ON TOP OF GUELPH-LOCKPORT
0 1 2 MILES
TILBURY W
STAPLES POOL
-600
-600
-500
-500
ESSEX COUNTY
KENT COUNTY
NEW WHEATLEY POOL
GOSFIELD N
MERSEA FIELD
WHEATLEY POOL
-400
M E R S E A
GOSFIELD S.
-400
LEAMINGTON
-300
KINGSVILLE
KINGSVILLE FIELD

FIG. 14

a day. According to Caley,[7] the structure of the Kingsville field is imperfectly known. Contours on top of the Guelph-Lockport formation (Fig. 14), based on limited control, show a west-trending, elongate dome with about 50 feet of closure. Some faulting appears to be present.

Mersea field.—Sixty wells, approximately 1,100 feet in depth, have been completed. Initial productions were fairly high, one well flowing 1,200 barrels a day, and another 400 barrels a day, but decline was very rapid. Only one set of samples, from a well drilled east of the field, is available. Stewart and Evans[8] have contoured the top of the Guelph on a basis of the depth of the main productive beds, which they consider is 40 feet below the top of the formation. This interpretation is given in Figure 14. The structure, as noted by Hume,[9] appears to be a long, narrow anticline with some suggestion of faulting.

Wheatley pool.—This small pool (Fig. 14) produced only 9,100 barrels from four wells. No information is available about structure.

New Wheatley pool.—This pool (Fig. 14) was discovered in 1948, and only one well, with an initial of 150 Mcf. from a depth of 1,200 feet, has been completed. This pool is structurally higher than the Wheatley pool on the southeast.

Staples pool.—This pool was discovered in 1948, and two productive wells have been completed, one a gas well with an initial of 400 Mcf. a day, and the other an oil well which came in with an initial of 140 barrels a day, but in a few days declined to 10 barrels a day. The upper part of the Guelph-Lockport produces from the depth of 1,250 feet. Contours on the top of the Guelph-Lockport suggest the presence of an elongate dome (Fig. 14), but the relatively steep dips on this horizon and the character of the well cuttings suggest reef conditions.

Tilbury field.—The Tilbury field (Fig. 15), in the southwestern part of Kent County, is the largest and most important Salina-Guelph field in the province. It has an areal extent of 17,000 acres. Caley[10] states

> that most wells are between 1,225 and 1,460 feet deep and do not penetrate below the Guelph-Lockport beds. Gas is found between 1,070 and 1,409 feet below the surface. Production comes from three principal zones, but many wells have four pay-streaks, and a considerable number indicate five, six or seven. The highest of the three main gas horizons is near the base of the Salina formation. The reservoir rock is fine- to dense-textured dolomite, usually containing small quantities of calcium sulphate. Yields from this horizon are commonly small and in many wells little more than shows of gas are encountered. The second producing zone is near the top of the Guelph formation and is as much as 80 feet below the productive Salina zone. The reservoir rock is light buff and grey, crystalline dolomite. This horizon usually yields gas in commercial quantity, and in some wells con-

[7] J. F. Caley, "Palaeozoic Geology of the Windsor-Sarnia Area," *Geol. Survey of Canada Mem. 240* (1945), p. 92.

[8] C. S. Evans and J. S. Stewart, "Gas and Oil in Southwestern Ontario," *Geol. Survey of Canada, unpublished manuscript.*

[9] G. S. Hume, "Oil and Gas in Eastern Canada," *Geol. Survey of Canada*, Econ. Geol. Ser., No. 9 (1932), p. 58.

[10] J. F. Caley, "Palaeozoic Geology of the Windsor-Sarnia Area, Ontario," *Geol. Survey of Canada Mem. 240* (1945), p. 81.

FIG. 14

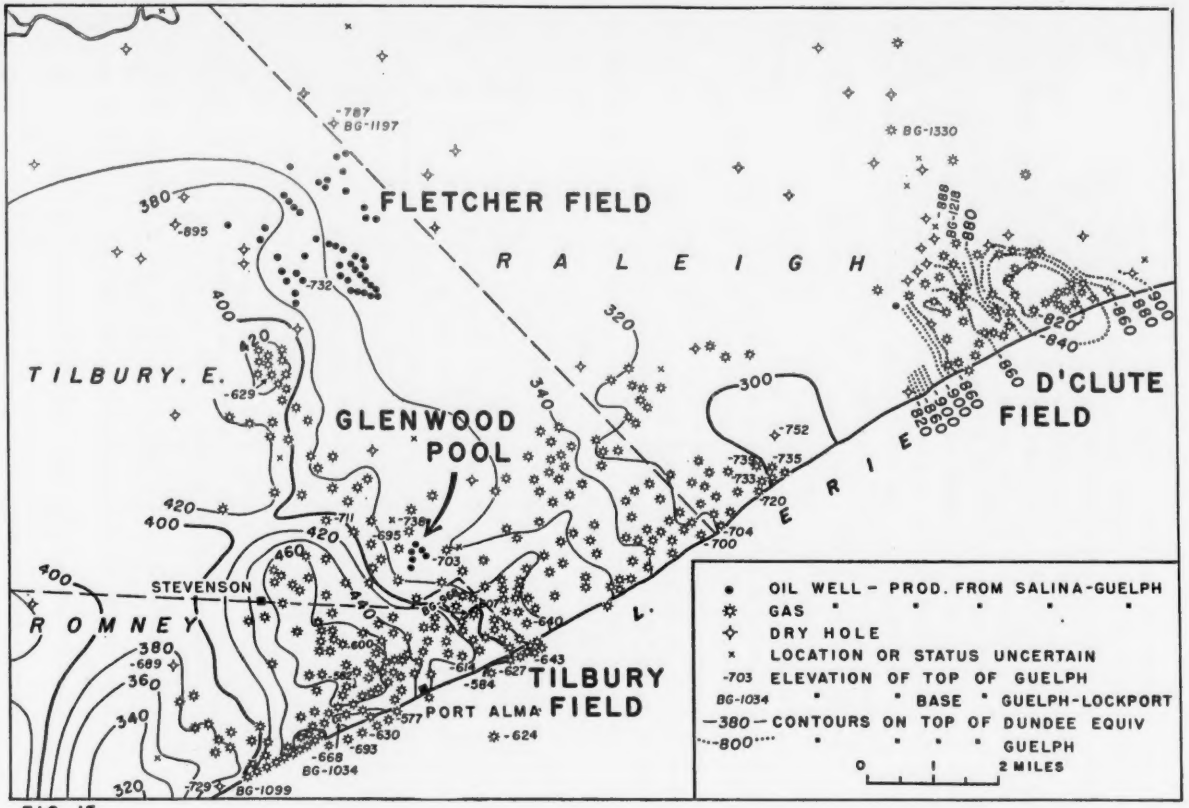

FLETCHER FIELD
RALEIGH
TILBURY. E.
GLENWOOD POOL
D'CLUTE FIELD
ERIE
STEVENSON
ROMNEY
L.
TILBURY FIELD
PORT ALMA
BG-1197
BG-1330
BG-1034
BG-1099
OIL WELL - PROD. FROM SALINA-GUELPH
GAS
DRY HOLE
LOCATION OR STATUS UNCERTAIN
-703 ELEVATION OF TOP OF GUELPH
BG-1034 BASE GUELPH-LOCKPORT
—380— CONTOURS ON TOP OF DUNDEE EQUIV
----800---- GUELPH
0 1 2 MILES

FIG. 15.

stitute the lowest productive zone. The third and lowest gas-bearing zone is also in the Guelph, and in places is more than 100 feet below the one above. The reservoir rock is grey, crystalline dolomite, essentially similar to that of the upper Guelph Zone. Some of the largest initial yields are from this horizon, but it commonly carries much water, and in many wells has been plugged off. Each of the two gas bearing zones in the Guelph contains more than one pay-streak, and such streaks may also be present in the intervals between the main producing zones. Thus the several pay-streaks are irregularly distributed throughout a vertical thickness of 200 feet. They appear to be lens-like in form, and are, therefore, difficult to correlate from well to well. During the early development of the field, wells with large initial open flow capacities were common. One well had an open flow of 7,000 MCF a day and many had capacities between 3,000 MCF and 5,000 MCF. . . . The structure of the Guelph formation in the Tilbury Field is difficult to portray. Cuttings for only thirty-eight of the total number of wells are available, and of these, cuttings for six are incomplete or are unreliable. Elevations on the top of the Guelph are therefore, impossible to determine except in the comparatively few wells for which reliable samples are available. Also it was impossible to place the Salina-Guelph contact in drillers' logs with assurance. However, as the Hamilton-Norfolk (Dundee Equivalent) contact is readily recognized by drillers their recordings of its depth furnish reliable data for calculations of elevations on this contact. Contours drawn on the Norfolk show a broad elongate dome [Fig. 15] trending north-west and extending from the lake to a point north of Stevenson. Closure of about 50 feet is indicated. Dips are gentle, averaging 70 feet a mile on the southwest flank and 40 feet a mile on the opposite side. A second, smaller dome, with perhaps 40 feet of closure is present at the extreme northern part of the field. A detailed study of depth of production in the Guelph, correlated with depth of production in those wells for which cuttings are available indicate that in general structure on this horizon (top of Guelph) roughly simulates that on the Norfolk formation above.

Evans[11] points out that from the few wells drilled through the Guelph in the Tilbury field for which there are samples, the Guelph is thicker in the field than in the non-productive area immediately surrounding it. Unfortunately, conclusive evidence about the exact nature of this trap is lacking, but the available facts suggest that accumulation was due to both structural and reef conditions.

Fletcher and Glenwood pools.—There are insufficient data to determine structural conditions in these pools (Fig. 15), but both appear to be downflank oil accumulations, related to the Tilbury gas field. The Fletcher field has produced 1,200,000 barrels of oil. The producing formations are the lower Salina and the Guelph, at depths of 1,400 feet. Initial rates varied from a few barrels to a few hundred barrels a day. In general, much salt water and gas accompanied the oil in this field.

D'Clute field.—This field (Fig. 15) is 4 miles east of the Tilbury field and the highest part of the top of the Guelph is more than 200 feet lower than the highest part of the Tilbury field. The principal gas zone is 1,500–1,580 feet below the surface and is within the upper 60 feet of the Guelph-Lockport. There may be several producing streaks in the general producing zone. There is also a smaller productive zone within the lower 80 feet of the Salina. Initial open flows range

[11] C. S. Evans, "Natural Gas Fields in Southwestern Ontario," *Canadian Gas Jour.* (October, 1944), supplement, p. 4.

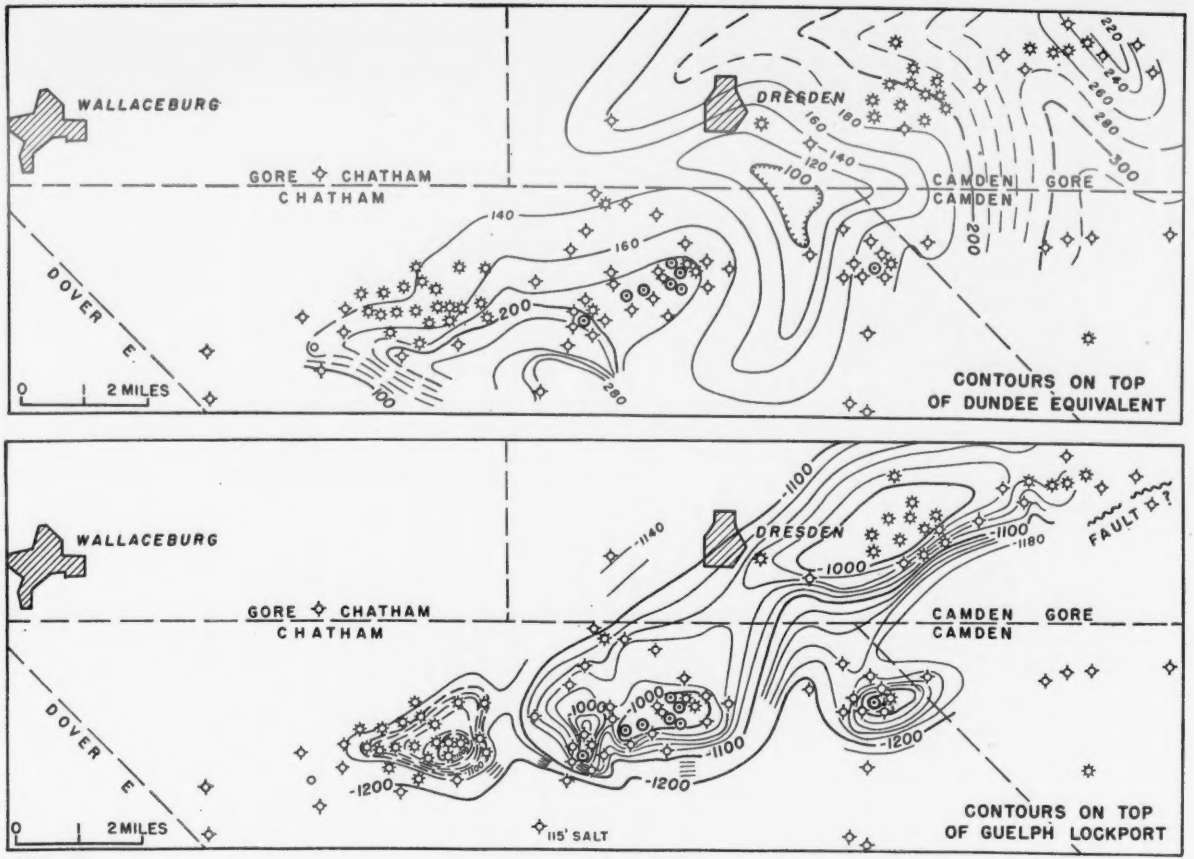


FIG. 16

GAS WELL- PROD. FROM SALINA ⊙ GAS WELL- PROD. FROM GUELPH

DRY HOLE

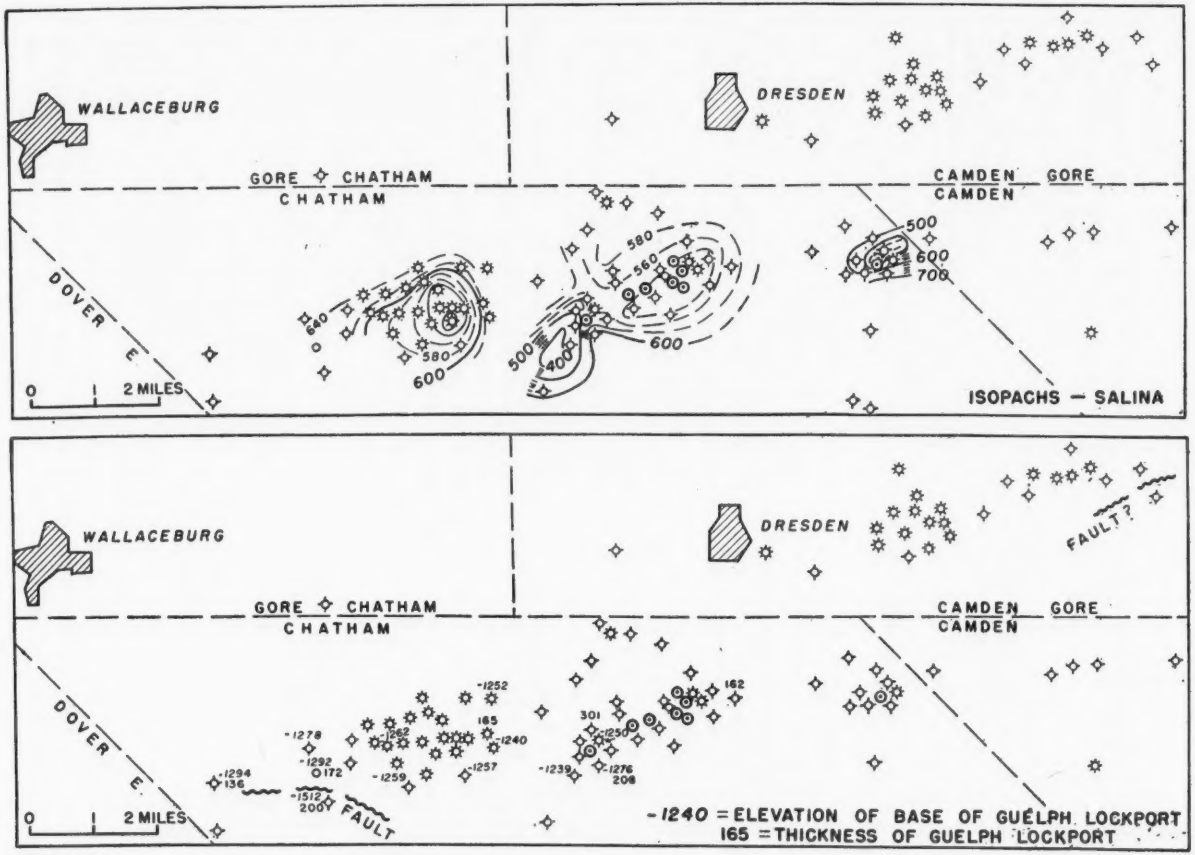


FIG. 17

GAS WELL - PROD. FROM SALINA ⊙ GAS WELL - PROD. FROM GUELPH

DRY HOLE

from 140 Mcf. to 24,000 Mcf. a day, and most of the wells initially produced more than 1,000 Mcf. a day. According to Evans,[12]

> the D'Clute field is made up of two anticlinal structures separated by a low faulted strip and bounded on outer sides by faults. In this field there is also an indication that the Guelph is thicker over the productive area than in the non-productive area immediately surrounding it. In general the two productive anticlines occur at the south part of, and below, an anticline on the near surface Big Lime (Dundee Equivalent) but in detail there is great variance from this. Just to the west of the field all formations are low and rise fairly steeply to the east. The Big Lime and other horizons above the Guelph rise progressively to a point that is right over the faulted low in the Guelph that is non-productive. Production from the Guelph and Salina in the west part of the field occurs to the west of the highest point found on the upper formations. From this high in the upper formations there is a marked drop to the eastward of these higher formations, while at depth the Guelph and Salina rise fairly steeply.

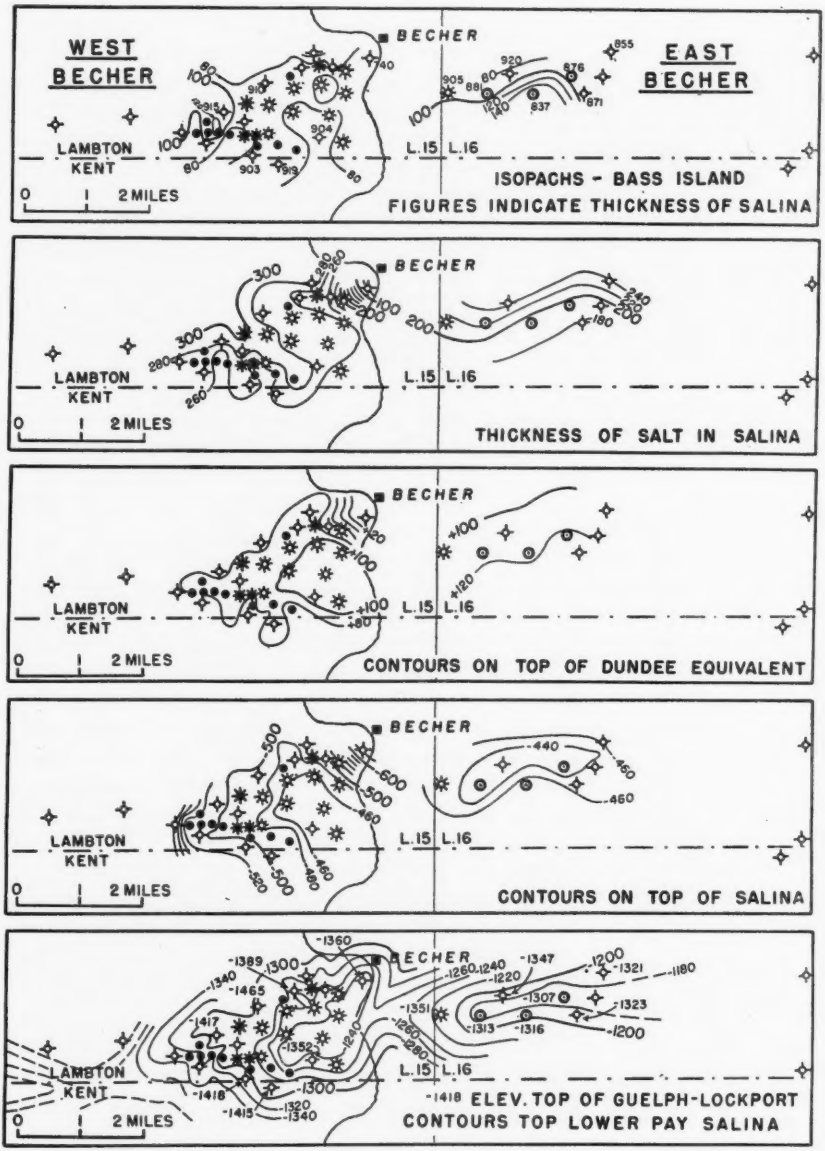
Chatham and Camden Gore fields.—(Figures 16 and 17.) Producing formations in the Chatham field (Figs. 16 and 17) are both the Salina and the Guelph-Lockport at depths of 1,425–1,625 feet. Initial yields range from 40 Mcf. to 600 Mcf. a day but two wells had initial yields of 2,000 Mcf. and 6,000 Mcf., respectively. Contours on top of the Guelph-Lockport indicate the presence of four small but pronounced dome-like highs that rise 100 feet or more above the surrounding Guelph-Lockport surface (Fig. 16). Contours on the top of the higher Dundee equivalent do not reflect these structures. The Salina overlying the top of these highs is much thinner than it is well down the flanks (Fig. 17) and the Guelph-Lockport is more than 300 feet thick on the high southwest of Dresden, compared with a thickness of 165 feet on the edge of the most westerly high. Elevations of the base of the Guelph-Lockport indicate that this horizon is almost flat-lying beneath the Chatham field. It is evident therefore, that the highs indicated by the contours on top of the Guelph-Lockport are reefs. Eight of the wells produce from the Guelph-Lockport and these are all on the top of the reefs. The initial yields from these wells are considerably larger than the initials of most of the remaining wells which produce from the Salina.

A fault is present south of the Chatham field (Fig. 17), having a displacement of more than 100 feet and the downthrown side on the south.

In the Camden Gore pool, the Salina is the producing formation, and the wells in general have initials of a few hundred thousand cubic feet a day. Contours on top of the Guelph indicate a dome with 25 feet of closure.

West Becher pool.—Nine gas wells, thirteen oil wells, and twelve dry holes have been completed in this pool. All oil and gas are produced in the "lower pay" of the Salina from depths of 1,850–1,925 feet. Initial production varies from 7 to 30 barrels a day of oil, before acidizing, and from 150 Mcf., to more than 2,000 Mcf. a day of gas. Contours on top of the "lower pay" of the Salina (Fig. 18) indicate a dome of 2,500 acres in areal extent. Amount of closure is not known and may range from 25 to 60 feet or more. This structure is reflected on the top of the

[12] C. S. Evans, *op. cit.*



● OIL WELL - PROD. FROM SALINA ✲ GAS WELL - PROD. FROM SALINA
⊙ GAS WELL - " " GUELPH ✧ DRY HOLE

FIG. 18

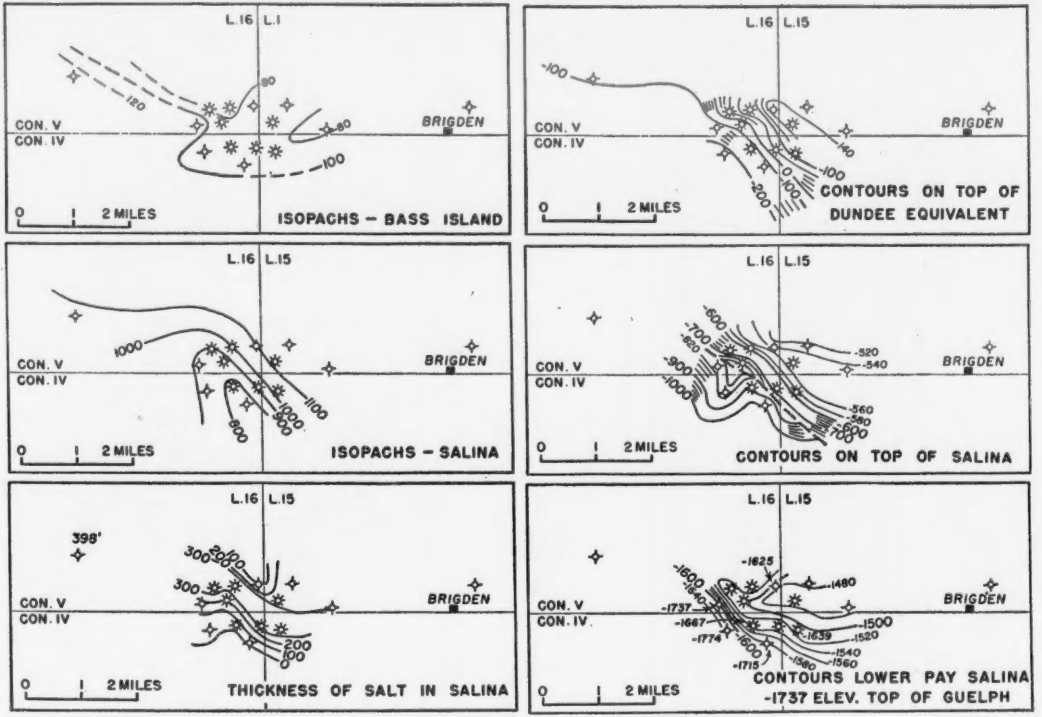

L.16 L.1
CON. V
CON. IV
BRIGDEN
0 1 2 MILES
ISOPACHS – BASS ISLAND
L.16 L.15
CONTOURS ON TOP OF DUNDEE EQUIVALENT
ISOPACHS – SALINA
CONTOURS ON TOP OF SALINA
398'
THICKNESS OF SALT IN SALINA
CONTOURS LOWER PAY SALINA
-1737 ELEV. TOP OF GUELPH
GAS WELL – PROD. FROM SALINA
DRY HOLE

FIG. 19

Salina and on the top of the Dundee equivalent, but on each of these horizons the structure becomes less pronounced. Elevations on the top of the Guelph suggest a similar, but slightly more pronounced fold. The few elevations that are available on the base of the Guelph suggest that structure is present at this horizon. Salt ranging from 100 to 300 feet thick is present in the Salina. Production is, in general, related to structure, but dry holes occur at various structural positions. The better wells occur along the minor re-entrants which may indicate small faults. Incipient fracturing is present in the few cores that have been obtained. The average thickness of the producing beds is 12.5 feet, average porosity 10 per cent, and permeability in one well was found to be 10.3 millidarcys. Water has not been encountered in the "lower pay." Without exception, the "lower pay" in the dry holes is composed of limestone, whereas in the productive wells, it consists of dolomite or dolomite and limestone.

East Becher pool.—This pool (Fig. 18) consists of three gas wells that had initials of 100 Mcf. to 500 Mcf. a day. It is 2 miles from the West Becher pool. Accumulation appears to occur in a small elongate dome in the Guelph-Lockport. The "lower pay" of the Salina has not yielded oil or gas in this area. It is composed largely of dolomite, but lacks porosity.

Kimball pool.—This pool was discovered in 1947, and to date seven gas wells and six dry holes have been completed. Two of the wells had good showings of oil. Initial production varies from 125 Mcf. to 1,250 Mcf. a day from depths of 2,100 feet in the "lower pay" of the Salina. Contours on the top of the "lower pay" (Fig. 19) suggest the presence of a dome of approximately 2,000 acres in extent, and with closure of 40 feet or more. A northwest-southeast fault appears to limit the pool on the southwest. The northerly and easterly limits have not been defined. In general, the structure on the "lower pay" is reflected by the higher formations. The salt absent in some places in the Salina, ranges in thickness to more than 300 feet. The few wells have been drilled to the Guelph-Lockport indicate that structure on this formation corresponds in general with that on the "lower pay" of the Salina. There is no evidence to suggest reef conditions in the Guelph-Lockport. As in the Becher field, both dry holes and productive wells occur at structurally high locations. In the dry holes, however, the producing beds were found to be composed of limestone, whereas in the productive wells, they are made up of dolomite or dolomitic limestone.

Dawn field.—The Dawn gas and oil field is composed of series of unrelated pools that extend over an area 12 miles in length, and less than 1 mile in width. Caley[13] has described this field as follows.

> The production was obtained from near the base of the Salina formation and from the upper part of the underlying Guelph, at depths of 1,813 to 1,955 feet. . . .
>
> Most of the wells within the present limits of the Dawn field are between 1,600 and 2,290 feet deep and do not penetrate below the Guelph-Lockport beds. Production is from

[13] J. F. Caley, "Palaeozoic Geology of the Windsor-Sarnia Area, Ontario," *Geol. Survey of Canada Mem. 240* (1945), pp. 67–69.

three general zones; two in the lower part of the Salina, and one in the upper part of the Guelph formation. Each of these may include several pay-streaks separated by non-productive intervals. The position of the two productive zones in the Salina formation seems to vary with reference to the top of the Guelph. The upper zone is as much as 320 feet, and the lower one as little as 5 feet, above the Guelph. Most of this variation appears to be due to the presence or absence of thick salt beds, or to relatively abrupt changes in the thicknesses of these beds from place to place. . . . The lowest producing horizon may be almost anywhere within the upper 100 feet of the Guelph formation.

Of the three general producing zones mentioned above, the highest yields only gas; the intermediate yields some gas and most of the oil; and the lowest horizon yields a little oil and more gas than the two Salina horizons combined. Initial yields of gas range from a few thousand to a million cubic feet a day, although several wells had much higher yields and a few are reported to have come in with yields of over 20 million cubic feet a day. The average initial yield of seven producing wells drilled during 1942 and 1943 was about 436 M cubic feet a day. . . . Initial yields of oil are from 1 to 25 barrels a day and one well is reported to have come in with 50 barrels a day. . . .

The structure of the Dawn field is difficult to determine. Contours on top of the Guelph formation are not entirely satisfactory, as reliable samples for many of the earlier wells are not available, and the Salina-Guelph contact is not determinable from drillers' logs. Also, not all wells reach to the top of the Guelph formation. However, the surface of the Guelph shows a series of elongate domes having an east-west trend and apparently separated by narrow, shallow troughs. Closure on these domes is from 20 to 100 feet, and dips range from 80 to 400 feet a mile. Offset to the south about 2 miles from the west end of the main field is another dome occupying lots 18 to 20, con. 1. This structure has 200 feet of closure and rises at a rate of about 800 feet a mile.

The Guelph-Lockport beds are known to vary from 90 to 278 feet in thickness. The more pronounced and restricted variations may be due to reefs that are built much higher than the adjacent strata, thus producing great local increases in thickness of the formation. Although the wells located on the highest part of the localized domes at the west end of the Dawn field do not pass completely through the Guelph-Lockport succession, it seems more logical to attribute these domes to reef structures than to folding of the beds.

Structure contours on top of the Guelph do not coincide with those drawn at the base of the Guelph-Lockport beds, nor with contours drawn on top of the Norfolk formation (Big Lime). Contours on the "Big Lime" indicate structural "lows" or depressions above high places on the surface of the Guelph. There is thus a divergence of structure between these two horizons. This may result from several causes. The long, narrow form of the main producing area is strongly suggestive of faulting. Faulting has not been detected in any of the well cuttings examined, but if present, could result in apparent variations in thickness of a formation in the case of wells that pass through the fault where it intersects the formation. Leaching of salt by waters circulating along a fracture zone might result in a settling of the overlying strata. Also, changes in thickness of the salt may be produced by flowage under differential pressure. This, too, might be followed by a subsidence of the beds overlying the salt-bearing formation.

There are places where structural "highs" on the Norfolk formation seem to be related to thick deposits of salt in the deeper, Salina beds. These "highs," on the other hand, are not always reflected on top of the Guelph formation, which may show a depression below a "high" on the Norfolk formation. This may indicate that in areas underlain by salt, the Norfolk is likely to be "high" where unusual thicknesses of salt occur in the Salina beds, and conversely, that the Guelph is apt to be "high" where salt beds in the overlying Salina are thin. However, it is strongly emphasized that available data are inadequate as a basis for interpreting the foregoing as a general rule. Thus, it should not be taken for granted

that a structural "high" on the "Big Lime," which is underlain by a thick salt section, will necessarily be above a "low" on the Guelph formation.

Accumulation in the Dawn field is controlled largely by structure and most of the producing wells are located fairly high on the several domes that constitute the field. In general, the largest producers are highest on the structure, although during recent years commercial production of gas has been obtained as much as 150 feet below the crest.

The accompanying maps (Figs. 20 and 21) illustrate the points mentioned in Caley's description of this field. They show the extent of the reef development in this area, and the relation of production to reefs and to structural development. It seems clear from the evidence available that an east-west fault of considerable displacement is situated south of the main production trend in this area.

Zone field.—Most of the gas in this field is produced from the "upper pay" of the Salina, although some wells produce from the "lower pay." Depths to production range from 1,400 to 1,600 feet. Initials vary from a few hundred thousand to one million cubic feet of gas per day. Figure 22 shows the structure on the top of the "upper pay" of the Salina. Evans[14] states that in general there is a structural high on the Guelph and lower Salina beneath a narrow east-west depression on the Dundee equivalent. Below high Dundee equivalent on the north and south, there is 100–200 feet of salt in the Salina and the Guelph-Lockport below that is low. Beneath the narrow depression on the Dundee equivalent, there is very little or no salt, and the lower Salina and Guelph-Lockport horizons are high. In one well, although the Guelph-Lockport was not commercially productive, there is clear indication that a reef projected upward from the Guelph into the Salina.

Brownsville field.—Ninety wells have been drilled in the Brownsville field (Fig. 23), of which more than 75 were commercial gas producers. One third of these wells had initials of more than 2,000 Mcf. a day, and two wells came in with a yield of 20,000–25,000 Mcf. a day. Gas is produced from the upper 55 feet of the Guelph-Lockport. Because of insufficient well samples, a reliable contour map of the top of the Guelph-Lockport can not be prepared. Evans[15] states:

> the water data indicates that the structure of the Brownsville field is only a minor modification of the regional dip, since the sulphur water from the Detroit River series rises in all wells to, or near the surface. Moreover, in one well, Preston No. 1, a sulphur water struck in the Guelph at 968 feet below the surface, rises to the top of the well.

Evans[16] also points out that the Guelph is thicker over the productive area than outside of it. It appears, therefore, that accumulation is due to the presence of a reef or residual mass in the top of the Guelph-Lockport.

Malahide field.—Since the discovery of this field (Fig. 24) in 1938, nearly 100 wells have been completed. Gas is produced from the upper 50 feet of the Guelph-

[14] C. S. Evans, *op. cit.*, p. 5.

[15] C. S. Evans, *Ontario Bur. Mines Rept.*, Vol. 46, Pt. 5 (1937), p. 100.

[16] C. S. Evans, "Natural Gas Fields in Southwestern Ontario," *Canadian Gas Jour.* (October, 1944), supplement, p. 5.

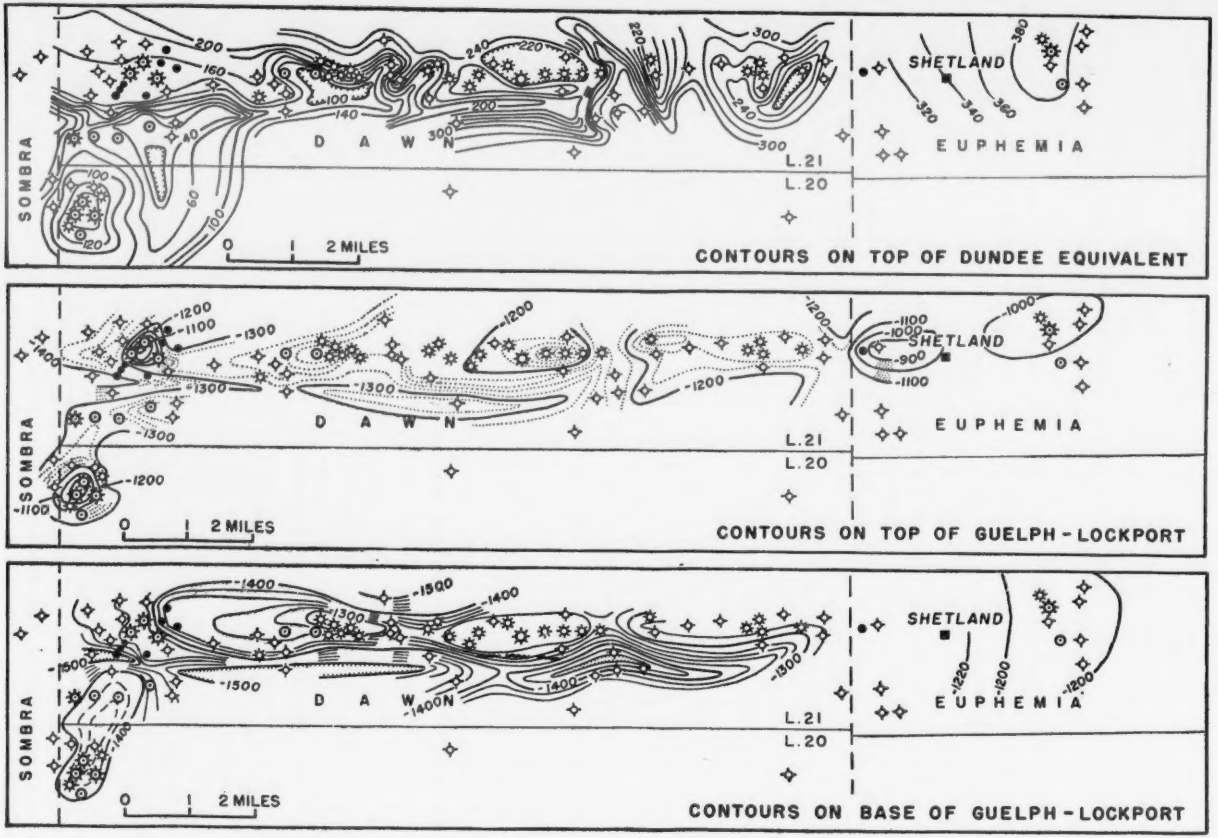


FIG. 20

● OIL WELL - PROD. FROM SALINA ✲ GAS WELL - PROD. FROM SALINA
⊙ GAS WELL - PROD. • GUELPH ✲ GAS WELL - • FROM SALINA & GUELPH
✧ DRY HOLE

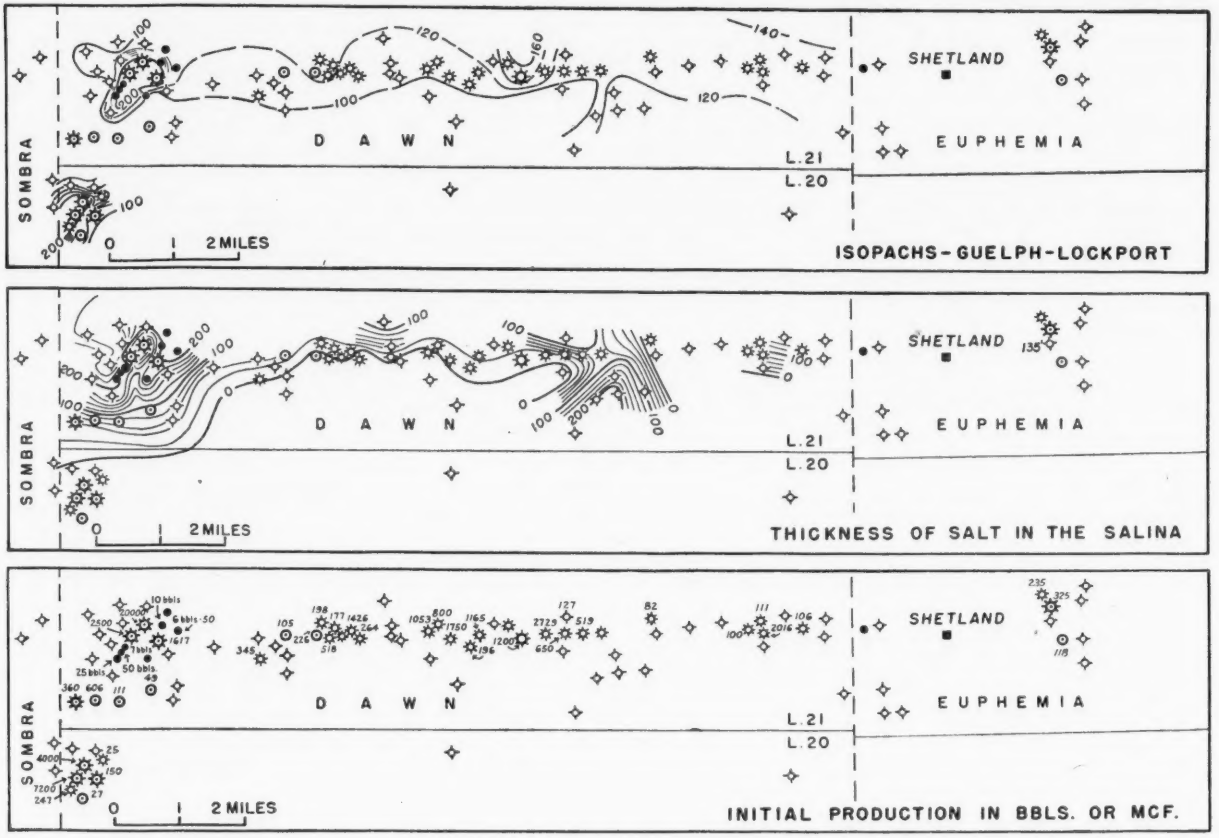


FIG. 21

● OIL WELL-PROD. FROM SALINA ✲ GAS WELL-PROD. FROM SALINA
⊙ GAS WELL-PROD. " GUELPH ✲ GAS WELL- " FROM SALINA & GUELPH
✧ DRY HOLE

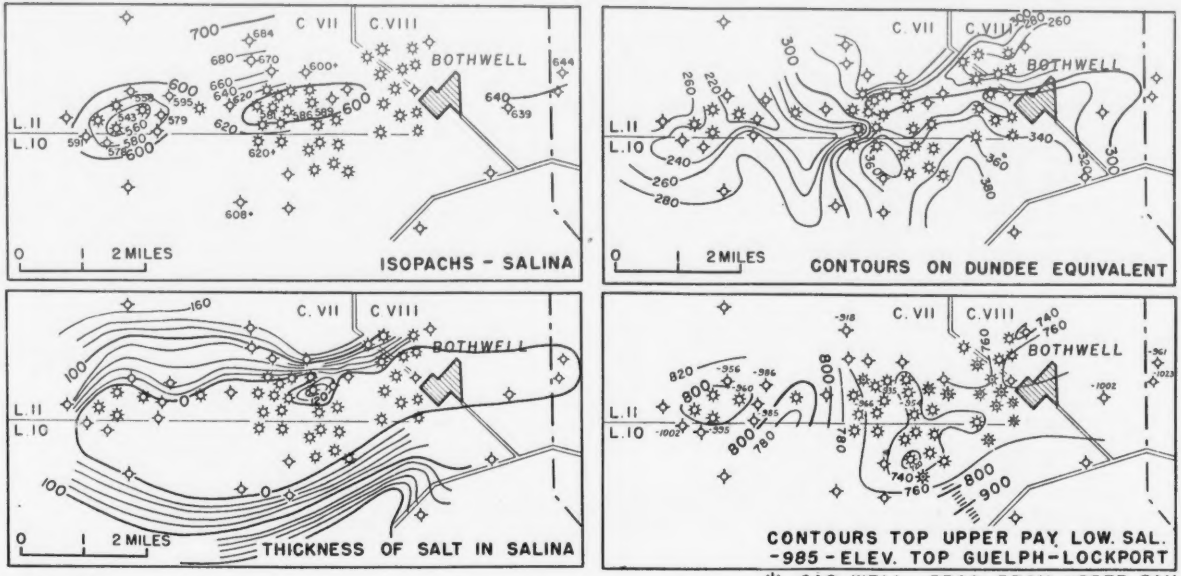


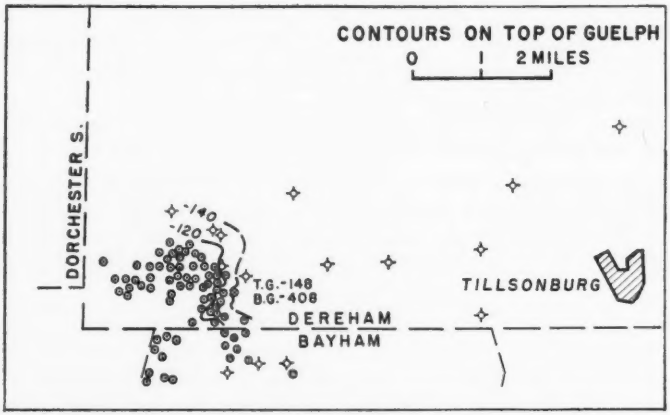
FIG. 22

GAS WELL - PROD. FROM SALINA

DRY HOLE

GAS WELL - PROD. FROM UPPER PAY

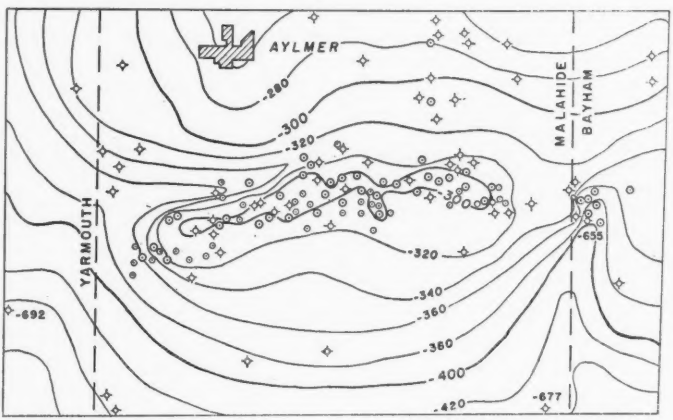
All elevations on top of Upper Pay of lower Salina should be minus (—).



⊙ GAS WELL-PROD. FROM GUELPH ✧ DRY HOLE

FIG. 23

Lockport. Drilling depths are approximately 1,100 feet and initials range from a few hundred thousand to 2 million cubic feet of gas per day. Contours on the top of the Guelph-Lockport suggest anticlinal conditions, but the Guelph-Lockport is known to be thicker over the productive area than in the adjacent area outside of it. The steepening of the contours north of the field suggests faulting in this vicinity.



⊙ GAS WELL-PROD. FROM GUELPH
✧ DRY HOLE
O WELL STATUS UNKNOWN

CONTOURS ON TOP OF GUELPH
FIGURES INDICATE ELEVATION OF BASE OF GUELPH

FIG. 24

Crumlin pool.—There is no information available concerning the possible factors controlling accumulation in this pool. Only seven wells were drilled and four of these had initials of 250–500 Mcf. a day from depths of approximately 925 feet, near the top of the Guelph-Lockport.

Pelee Island.—Twenty-nine wells have been drilled on Pelee Island to depths of 740–904 feet. Several of these had initials of 5–10 barrels of oil a day and considerable gas. However, a total of only 5,000 barrels appears to have been produced. The oil and gas were apparently obtained from the Salina. Exposures of Devonian rocks and the meager subsurface information available suggest that an east-west anticline with dips ranging up to 120 feet per mile crosses the island.

CONCLUSION

The evidence submitted suggests that facies changes in the A unit of the Salina are of prime importance in the pooling of oil or gas in this formation, and that where favorable facies are present in conjunction with folding and faulting some accumulation of these substances is likely to have taken place. In the absence of favorable facies, however, structures will probably be found dry.

Accumulation in the Guelph-Lockport seems to be primarily, if not entirely, due to the presence of reefs. Faulting appears to be present in most areas of reef development and appears to have been a contributing factor to this development.

The nature of the factors which seem to be of prime importance in the pooling of oil and gas in the Salina and Guelph formations are such that surface geology and geophysical methods are of little aid in exploration; consequently, the finding rate is low. Over the 50 years since the discovery of oil and gas in the Salina-Guelph, only one wildcat in 30 has resulted in a discovery. Much of this drilling, however, was done in the late 1890's and early 1900's, and wells were located on little or no basis whatever. Recent Salina-Guelph exploration has yielded one discovery for every ten wildcats. The pools are small with ultimates ranging from 1 to 10 billion cubic feet of gas, and probably a few hundred thousand barrels of oil. Drilling costs, however, are low, and in most areas a producing well can be completed for $5,000–$10,000. In the total area underlain by the Salina-Guelph, only one well has been drilled to every 16 square miles. Most of this drilling has been done in the area south of the line joining Hamilton and Sarnia. On the basis of present geological knowledge, there is no reason to feel that considerable of the large area east of Lake Huron and north of this line does not offer just as attractive prospects for gas or oil production in the Salina and Guelph-Lockport formations as the area on the south. Only 30 wells, or one well to 130 square miles, have been drilled in this area. The problem, perhaps, is not so much one of the likelihood of the presence of small Salina-Guelph pools, but rather the question of whether pools of such small areal extent can be located at a cost which will permit a reasonable return on the capital involved commensurate with the risk which must be taken.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 2 (FEBRUARY, 1949), PP. 189-222, 12 FIGS.

PALEOZOIC STRATIGRAPHY ALONG ALASKA HIGHWAY IN NORTHEASTERN BRITISH COLUMBIA[1]

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Madison, Wisconsin, and New York, N. Y.

ABSTRACT

Excellent exposures of Paleozoic rocks are present along the Alaska Highway between Summit Lake (mile 392) and the Liard River (mile 497) in British Columbia. Silurian, Devonian, and Mississippian beds have been studied in detail in this area. The names McConnell and Muncho are proposed for two unnamed Devonian formations in the area, and the name Kindle is introduced for all of the Mississippian rocks along this part of the highway.

Marine limestones and black shales make up most of the Paleozoic section although local sandstones are developed. The geologic record indicates that at least several hundred irregular but clearly cyclic sedimentary alternations occurred here during the Paleozoic era. In addition, several groups of cycles give evidence of megacyclic sedimentation.

The area is divided into three physiographic provinces: the Stone Range and the Sentinel Range, each of which is composed of tightly folded, overthrust, Paleozoic limestones, and the Racing River Valley, a relatively low gently folded zone of soft Upper Paleozoic and Mesozoic rocks which separates the two ranges. The Stone Range, on the east side of the area, is characterized by a thinner, more sandy, more variable sequence of Paleozoic rocks than the Sentinel Range, which seems to indicate closer proximity to the eastern shore of the Cordilleran geosyncline.

INTRODUCTION

An almost complete lack of transportation has been very discouraging to geologic investigation in most of northwestern Canada. This has been especially true in northeastern British Columbia, since this region lacks the valuable minerals which draw prospectors and their attendant geologic work. As a result, geological information concerning the area covered by this report was not available before the advent of the Alaska Highway. With construction of the highway, however, large geologically unexplored areas have been made relatively accessible for the first time.

During the summer of 1946, a small geologic party from the University of Kansas was granted permission to drive over the highway. Originally this group planned to study the Paleozoic geology of the South Nahanni River area in the southern part of the Yukon Territory. Because of transportation difficulties this was not possible. Excellent exposures of Paleozoic rocks had been observed along the Alaska Highway in northeastern British Columbia, and since these were easily accessible it was decided to substitute a study of these for the original plan.

Shortly after beginning the work, a remarkable cyclic alternation of beds was recognized, and was soon found to be present through practically the entire Paleozoic section. The writers present geologic observations of these rocks, and describe particularly the cyclic character (Fig. 1).

[1] Manuscript received, October 14, 1948.

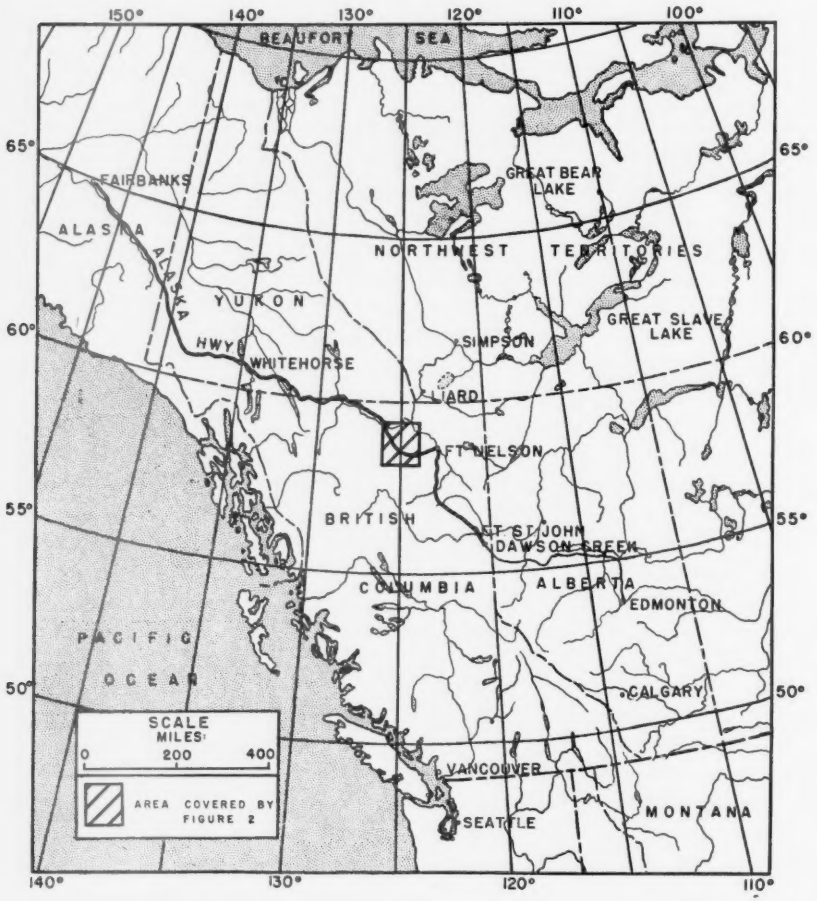
[2] Department of geology, University of Wisconsin.

[3] Department of geology, Columbia University.

PREVIOUS GEOLOGIC WORK

Little geologic information has been published on the area. The preliminary exploratory work of Dawson (1888), McConnell (1891), Hume (1923), and Cameron and Warren (1938), was limited to areas somewhat north of this region.

Text Figure 1 Map Showing Location of Area



A reconnaissance report of the structure and stratigraphy along this section of the Alaska Highway was presented by M. Y. Williams (1944) in connection with preliminary engineering surveys. The information presented here is intended principally to add to the observations made by Williams.

A generalized section showing the stratigraphic sequence in the area, with comments concerning the Mississippian beds, was recently published by Laudon and Chronic (1947, pp. 1610–18).

REGIONAL GEOLOGY

The rocks exposed between miles 380 and 497 along the Alaska Highway range in age from pre-Cambrian to Triassic. The major regional structures in the area have been produced by compression from the southwest in connection with late Mesozoic orogeny. Since Cretaceous rocks are involved in the structures the

TEXT FIGURE 2 FORMATIONS EXPOSED IN AREA.

MESOZOIC	TRIASSIC		Black sh. and black ls.
PALEOZOIC	MISSISSIPPIAN	KINDLE	Gray, silty ls. and chert
	DEVONIAN	FT. CREEK	Black, pyritic sh.
		RAMPARTS	Massive, tan, gray, and black ls.
		MUNCHO	Gray and black ls.
		MCCONNELL	Gray and black ls.
	SILURIAN	RONNING	Gray and black, cherty, dolomitic ls.
	CAMBRIAN ?	MACDOUGAL	Tan sandstone
PRE-CAMBRIAN			Quartzite, marble, schist, and basic igneous rocks

main deformation must have been post-Cretaceous in this area. At present the more resistant early Paleozoic and pre-Cambrian rocks are exposed in parallel mountain ranges trending N. 22° W. (Fig. 2).

It is convenient to recognize four physiographic zones in the area. (1) The foothills belt extends from the vicinity of Fort Nelson west to within 5 miles of Summit Lake. Lightly folded Mesozoic rocks predominate in this belt except along the western edge where upper Paleozoics are found locally. (2) The high rugged Stone Range composed of overthrust pre-Cambrian and early Paleozoic rocks crosses the highway in the vicinity of Summit Lake. (3) The Racing River valley, west of the Stone Range, is an area of low subdued topography composed mainly of late Paleozoic and early Mesozoic rocks. The regional structure of the

valley is synclinal although it is complicated by many minor folds and faults. (9) The Sentinel Range lies on the west of the Racing River Valley and is crossed by the highway in the gorge of the upper Toad River Valley. Pre-Cambrian and early Paleozoic rocks are intensely faulted in the range and form spectacular, high, barren, snow-covered peaks.

Rocks of probable pre-Cambrian age composed of quartzites, schists, slates, and marbles intruded by basic igneous bodies are exposed in the area.

The Cambrian system is represented by a thin series of tan quartzitic sandstones exposed principally in the Trout River Valley. As no fossils were found in these beds, their age can be based only on stratigraphic position and lithologic similarity to known Cambrian beds in adjoining regions. Since detailed studies of pre-Silurian rocks were not made, it is quite possible that other strata exposed in the area may also be Cambrian in age.

A single formation represents the Silurian system in this area. It is approximately 1,200 feet thick at its maximum development, and consists of banded, black and dark gray dolomitic limestones. Fairly abundant, corals and brachiopods indicate that it is entirely Niagaran in age, and both fauna and lithologic character suggest correlation with the Ronning formation of the Mackenzie Mountains.

The Devonian system consists of four formations, the lower two of which have not previously been described and can be referred to the Devonian only tentatively because they lack diagnostic fossils.

The name McConnell is here proposed for the series of alternating black and gray limestones that rest unconformably on the Ronning formation and are overlain unconformably by the Muncho formation. The type section is located in the Sentinel Range above the Ronning formation east of mile 472 on a secondary peak west of Mt. McConnell on the Alaska Highway, where its thickness is approximately 680 feet. Mt. McConnell Peak is a new name proposed for the high peak in the Sentinel Range directly east of mile 472 on the Alaska Highway. The basal few inches of the formation consist of red and brown oxidized quartz sandstone which is replaced upward by a cyclic series of gray, massive, fine-grained limestones alternating with much darker gray, relatively thin-bedded, shaly limestones.

The name Muncho is here proposed for the group of alternating black and gray Devonian limestone beds that rest unconformably on the McConnell formation and are separated from the overlying Ramparts formation by a marked erosional unconformity. The type section is located in the same area as that of the underlying McConnell. Lithologically the Muncho formation is somewhat similar to the underlying McConnell. Its thickness is approximately 600 feet in the type section. A thin, sandy, oxidized conglomerate lies at the base of this formation and is followed by cyclic alternations of light gray, relatively massive limestones, and soft, thin-bedded, much darker gray limestones.

Three distinct members all remarkably cyclic make up the thick Ramparts formation, which overlies the Muncho at most localities. The lowest is a series of

yellow, sandy to silty, limestone beds, the middle a group of white, massive, cliff-forming limestone beds, and the upper a series of dark gray to black limestone beds.

The Ramparts formation is more than 1,500 feet thick, and forms a large part of the rugged topography characteristic of the Sentinel and Stone ranges.

The Fort Creek shale rests unconformably on the Ramparts formation. Black shaly limestones form the basal beds, but they are succeeded upward by a thick sequence of black, platy, hard, pyritic shale which forms the major part of the formation. The maximum observed thickness of the Fort Creek is slightly more than 800 feet. Because it is softer and less competent than the beds above and below, the Fort Creek often acted as the gliding plane for thrust-faulting in the area. As a consequence, its observed thickness is variable and the formation is rarely complete in any exposure. No cyclic alternation of beds was recognized.

The name Kindle is here proposed for the entire section of Mississippian rocks in the area. This formation lies unconformably on the Devonian, Fort Creek formation, and is unconformably overlain by Triassic beds. The type section is on the east side of a small tributary of the Toad River, approximately ½ mile south of the Alaska Highway in mile 428, on a small ridge approximately ½ mile west of Mt. Kindle. The new name Mt. Kindle is proposed here for the conspicuous mountain peak south of mile 427 on the Alaska Highway. Here the formation is composed of two members: a lower group of calcareous siltstones and an upper group of thin-bedded, cherty limestones, both of which exhibit marked cyclic bedding. Since the Kindle was deposited on a rough erosional surface, and was eroded prior to later deposition, its thickness varies greatly. In the type section, it is 291 feet; its maximum observed development is approximately 400 feet.

Triassic beds rest with erosional disconformity on the Kindle formation although they appear essentially conformable in both sections where the contact was observed. These beds are black, soft, calcareous shales and are poorly exposed. They are overlain by considerable thicknesses of shaly limestones. No attempt was made by the writers to determine the thickness of any post-Paleozoic formations. McLearn (1946, p. 3) reports an incomplete section of 500 feet of Triassic beds, and a much greater thickness of Jurassic and Cretaceous rocks, in this area.

STRATIGRAPHY

In order to show the characteristic, striking erosional expression of the individual beds, the sections described in this paper have been diagrammed to scale and the relative, though not exact, exposure pattern and lithologic character of each bed have been indicated. The sections are continuous in each figure, and show the oldest beds in the lower left corner, the youngest in the upper right. In four localities, more than one figure was required to delineate the complete section.

Individual cycles are numbered, where possible, beginning with the oldest recognizable unit in each formation. Division of sedimentary alternations into cycles has been made arbitrarily at the base of the darker, generally softer bed.

The lower units of the cycles are therefore darker in color and weather relatively rapidly, while the upper are commonly almost white and form most of the prominent scarps in the area. There are, of course, many variations in this oversimplified explanation of units, but to a surprising extent the simple alternations prevail throughout the sections studied.

The following discussion of sections is arranged physiographically, beginning in the northwest, where the Paleozoic sequence is thickest (Fig 3).

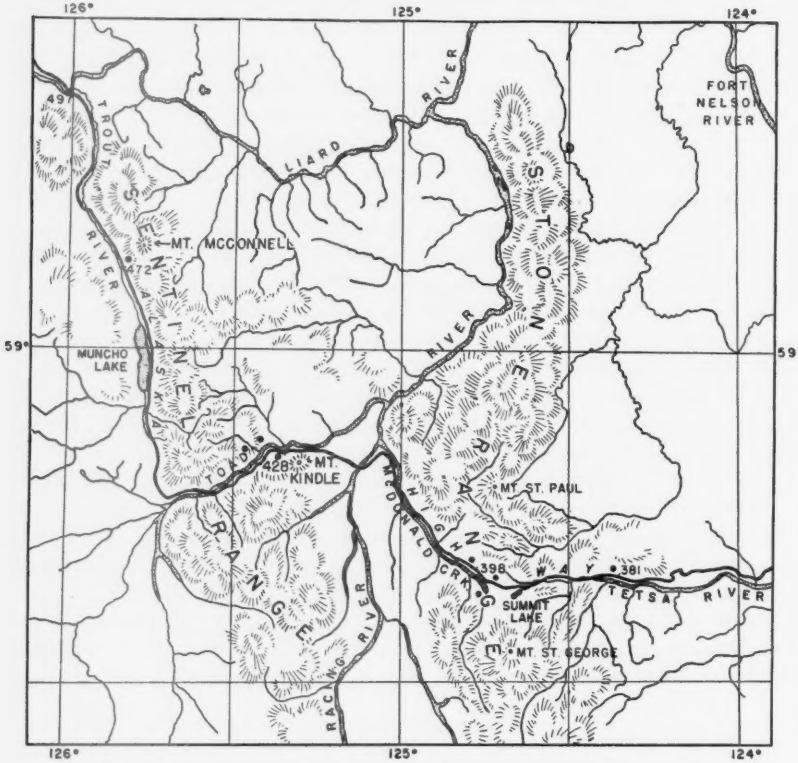


FIGURE 3 – SKETCH MAP SHOWING LOCATION OF SECTIONS MEASURED ALONG THE ALASKA HIGHWAY. THE MILEAGES ARE FROM DAWSON CREEK, BRITISH COLUMBIA.

Approx. scale: 1 inch equals 18 miles.

SENTINEL RANGE AREA

This general area comprises the western mountainous belt of Lower and Middle Paleozoic limestone fault blocks. The Sentinel Range is much more complexly

folded and faulted than the Stone Range. In one zone of 2 miles, across the general strike of the range, ten extensive thrust faults were observed.

Because of such structural complexities, it was very difficult to locate and measure any complete sections. Of the several sections studied, those along upper Trout River and Toad River have been selected as together illustrating the most typical Paleozoic section in the Sentinel Range. The two areas lie approximately 40 miles apart by road. Stratigraphically, however, they are similar, and seem to represent the same type of depositional environment in the Paleozoic basin (Fig. 4).

TROUT RIVER SECTION

The Trout River flows northwestward down a glacial valley from Muncho Lake to Liard River. It is parallel with the general trend of the Sentinel Range and finally cuts through the northern extension of the range to join the Liard River. Excellent exposures of Lower Paleozoic rocks are found in the canyons of streams tributary to the Trout River. One very thick, uncomplicated section was studied in the north canyon wall of a small stream entering Trout River from the east, near mile 472 on the Alaska Highway (Figs. 5a and 5b).

Deformed pre-Cambrian schists and quartzites are exposed along the lower walls of this small canyon. They are overlain unconformably by relatively flat, yellow to tan, rather coarse-grained, quartz sandstone beds. In this section the total thickness of the sandstones is approximately 450 feet. The lithologic character is similar to that of the Cambrian MacDougal series (Hume and Link, 1945, p. 9) which was studied by the senior writer in Imperial Canyon of the Mackenzie Mountains. No fossils were found in the sandstones; they are assigned tentatively to the Cambrian system on the basis of stratigraphic position and lithologic character. Williams (1944, p. 14) reported beds of "probable" Cambrian age approaching a thickness of 5,000 feet in the range west of Trout River Valley.

Ronning formation.—The Silurian system is represented by the Ronning formation, a series of limestone beds attaining a thickness of 1,200 feet. The basal 100 feet of the formation consist of black, obscurely bedded, very shaly limestone beds. Weathered exposures appear as black, shaly slopes. A small species of *Pentamerus* is abundant in the lower beds; specimens of *Halysites*, *Favosites*, and *Heliolites* were found near the top of the shaly zone, which is overlain by 50 feet of gray, massive, dolomitic limestone. No evidence of cyclic sedimentation was observed in these lower units, which together seem to make up one thick cycle similar to the overlying thinner ones.

The upper part of the Ronning, comprising 1,030 feet of sediments, consists of a perfectly developed cyclic sequence of dolomitic limestones. The dark units are characterized by relatively thin-bedded, black, shaly limestone beds which are almost everywhere fossiliferous. The light units consisted of slightly more massive, gray, relatively pure, dolomitic limestones, normally barren of fossils. In general, the lower cycles are characterized by comparatively thick dark units,

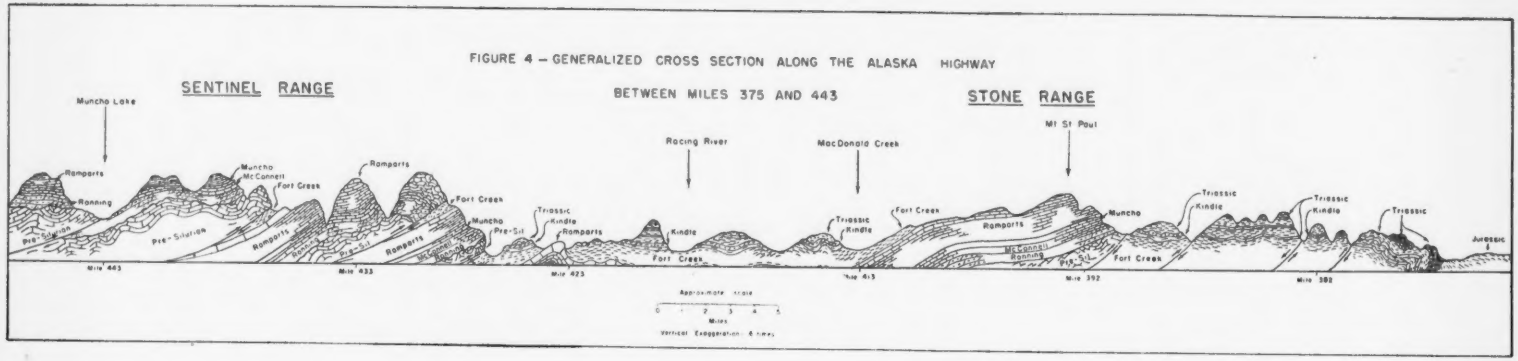


FIGURE 4 – GENERALIZED CROSS SECTION ALONG THE ALASKA HIGHWAY BETWEEN MILES 375 AND 443

but near the top of the formation these gradually become thinner. The light units are somewhat variable but relatively thin throughout.

Fossils in the Ronning formation, with the exception of those in the basal shales, are largely silicified. What appear to be masses of silicified calcareous algae far outnumber all other organic remains. Some of the beds in cycles 26 and 30 contain as much as 50 per cent by volume of this algal chert. Silicified corals occur intermingled with the algal masses. Except for *Pentamerus* sp., the fossils of the fauna are corals: *Favosites niagarensis* Hall, *Favosites favosus* (Goldfuss), *Halysites catenulatus* (Linnaeus), *Heliolites megastoma* McCoy, *Amplexus shumardi* (Edwards and Haime), *Stombodes* sp., and several species each of *Zaphrentis* and *Cyathophyllum*. This fauna is characteristic of Middle Silurian (Niagaran) sediments in many parts of the world.

The contact between the Ronning and the overlying McConnell formation is sharply unconformable, with evidence of considerable relief. The unconformity increases in magnitude toward the east.

McConnell formation.—The lowermost Devonian formation represented at mile 472 is the McConnell formation, an alternating sequence of black and gray limestones, predominantly clastic near the base but becoming less clastic upward. The cyclic nature of the formation is demonstrated even in the lower beds where thicker calcareous units represent the light limestone, and thin shale beds represent the more clastic, dark units. Generally the light gray, pure limestone units are thicker in the lower part of the formation; they thin markedly toward the top. The darker, shaly units become thicker upward (Figs. 6a and 6b).

Beginning in the upper part of cycle 52, there is a break-down of regular cyclic sedimentation. Massive, poorly bedded, porous, dolomitic limestone occurs below the unconformity separating the McConnell formation from the overlying Muncho. A thin, laminated, sandy limestone bed with some indication of current action lies at the contact.

Muncho formation.—The Muncho formation rests unconformably on the McConnell. Lithologically it resembles the latter, and has a similar pattern of deposition. A thin, sandy, oxidized conglomerate lies at the base of the section. This is overlain by a series of black, soft, shaly limestones which alternate with beds of gray, relatively massive limestone, forming clearly defined cycles to the top of the formation.

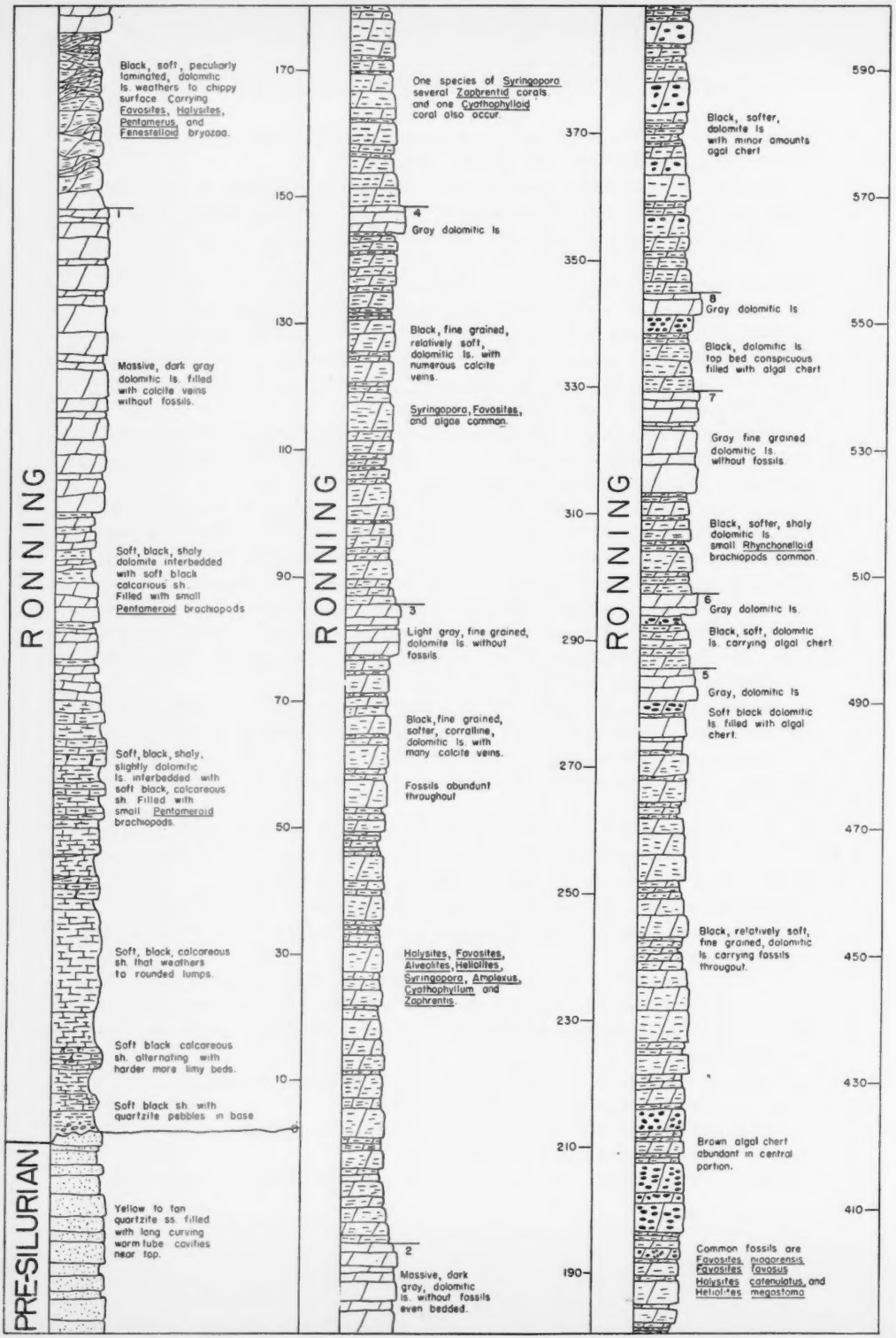
In the lower part of the Muncho formation, the light limestone units are thicker, generally thinning upward; the dark units are relatively thin near the base and become thicker upward, an exact reversal of the pattern in the underlying McConnell.

Since no fossils were observed in the Muncho formation, its precise position in the Devonian system could not be determined.

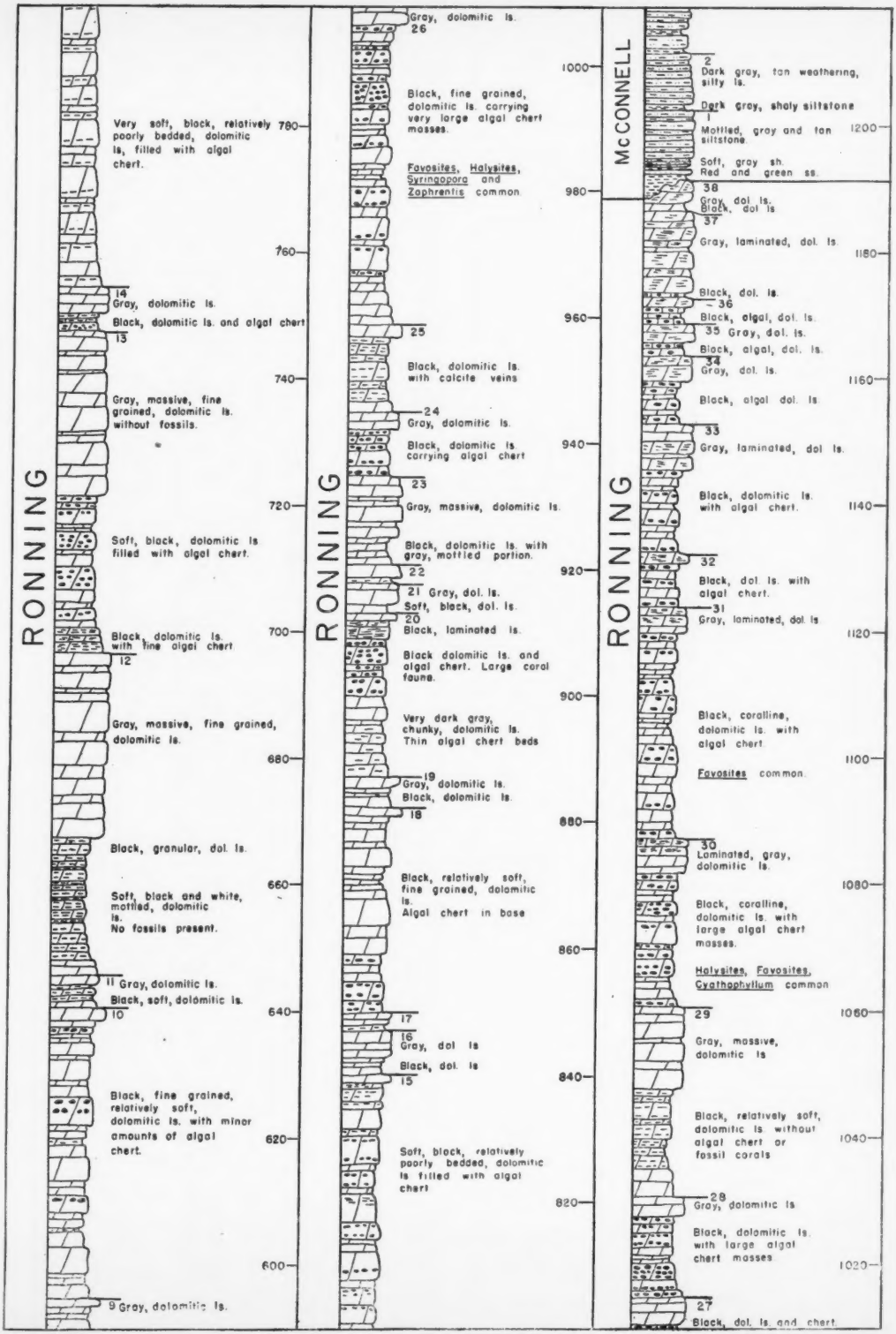
Erosional contact with the Ramparts formation is distinct and sharp, but there is little evidence of relief on the surface.

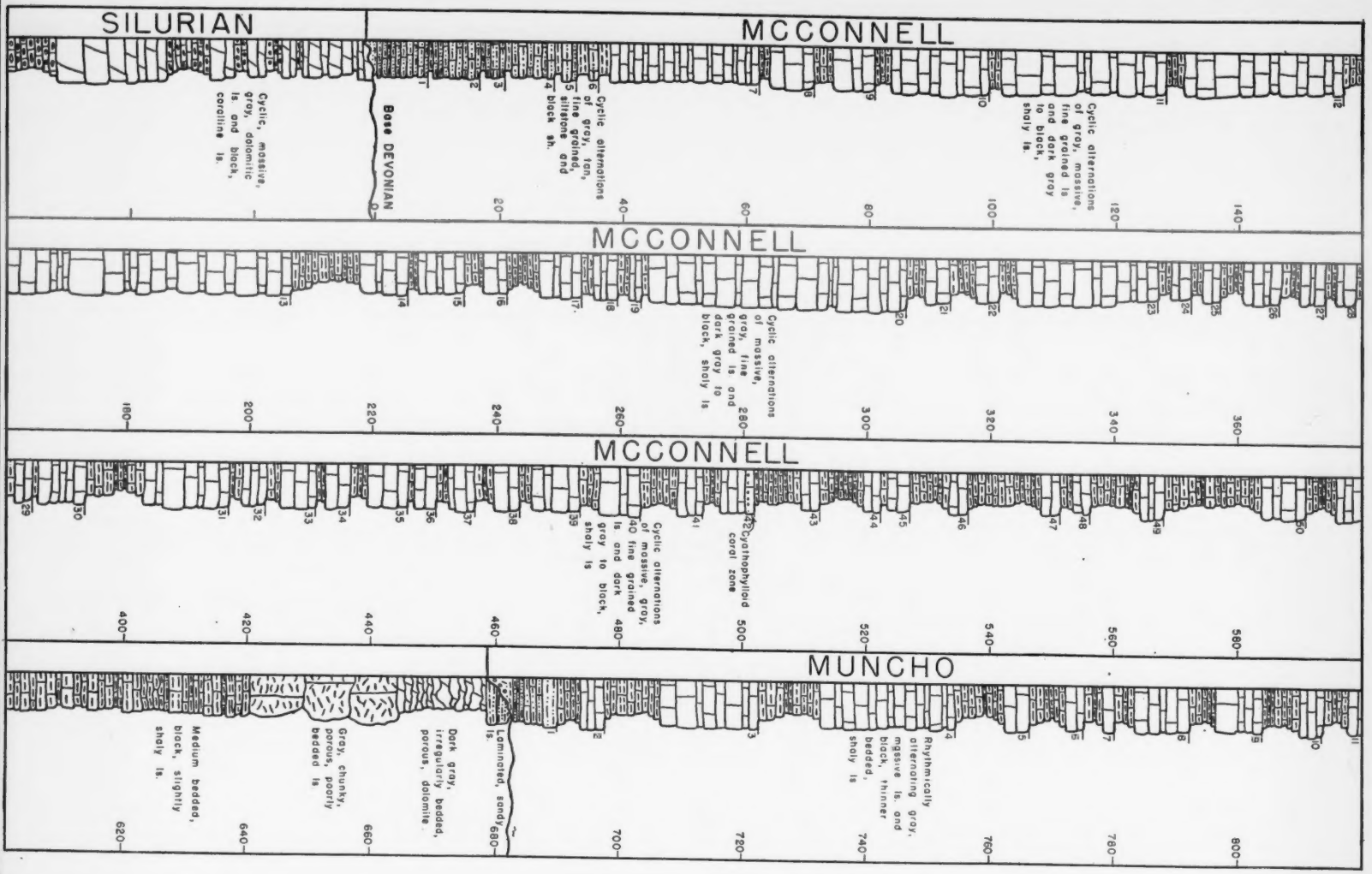
Ramparts formation.—The lower beds of this formation cap the mountain

Text Figure 5a Ronning Formation, Trout River Valley, Mile 472, Alaska Highway.


RONNING
PRE-SILURIAN
Black, soft, peculiarly laminated, dolomitic ls. weathers to chippy surface. Carrying Favosites, Halysites, Pentamerus, and Fenestelloid bryozoa.
Massive, dark gray dolomitic ls. filled with calcite veins without fossils.
Soft, black, shaly dolomite interbedded with soft black calcarious sh. Filled with small Pentameroid brachiopods
Soft, black, shaly, slightly dolomitic ls. interbedded with soft black, calcareous sh. Filled with small Pentameroid brachiopods.
Soft, black, calcareous sh. that weathers to rounded lumps.
Soft black calcareous sh. alternating with harder more limy beds.
Soft black sh. with quartzite pebbles in base
Yellow to tan quartzite ss. filled with long curving worm tube cavities near top.
170
150
130
110
90
70
50
30
10
0
1
RONNING
One species of Syringopora several Zaphrentid corals. and one Cyathophylloid coral also occur.
4
Gray dolomitic ls
Black, fine grained, relatively soft, dolomitic ls. with numerous calcite veins.
Syringopora, Favosites, and algae common.
3
Light gray, fine grained, dolomite ls. without fossils.
Black, fine grained, softer, corralline, dolomitic ls. with many calcite veins.
Fossils abundunt throughout
Halysites, Favosites, Alveolites, Heliolites, Syringopora, Amplexus, Cyathophyllum and Zaphrentis.
2
Massive, dark gray, dolomitic ls. without fossils even bedded.
370
350
330
310
290
270
250
230
210
190
RONNING
Black, softer, dolomite ls with minor amounts algal chert
8
Gray dolomitic ls
Black, dolomitic ls. top bed conspicuous filled with algal chert
7
Gray fine grained dolomitic ls. without fossils.
Black, softer, shaly dolomitic ls. small Rhynchonelloid brachiopods common.
6
Gray dolomitic ls.
Black, soft, dolomitic ls. carrying algal chert
5
Gray, dolomitic ls
Soft black dolomitic ls. filled with algal chert.
Black, relatively soft, fine grained, dolomitic ls carrying fossils througout.
Brown algal chert abundant in central portion.
Common fossils are Favosites niagarensis Favosites favosus Halysites catenulatus, and Heliolites megastoma
590
570
550
530
510
490
470
450
430
410

Text Figure 5b Ronning Formation, Trout River Valley, Mile 472, Alaska Highway



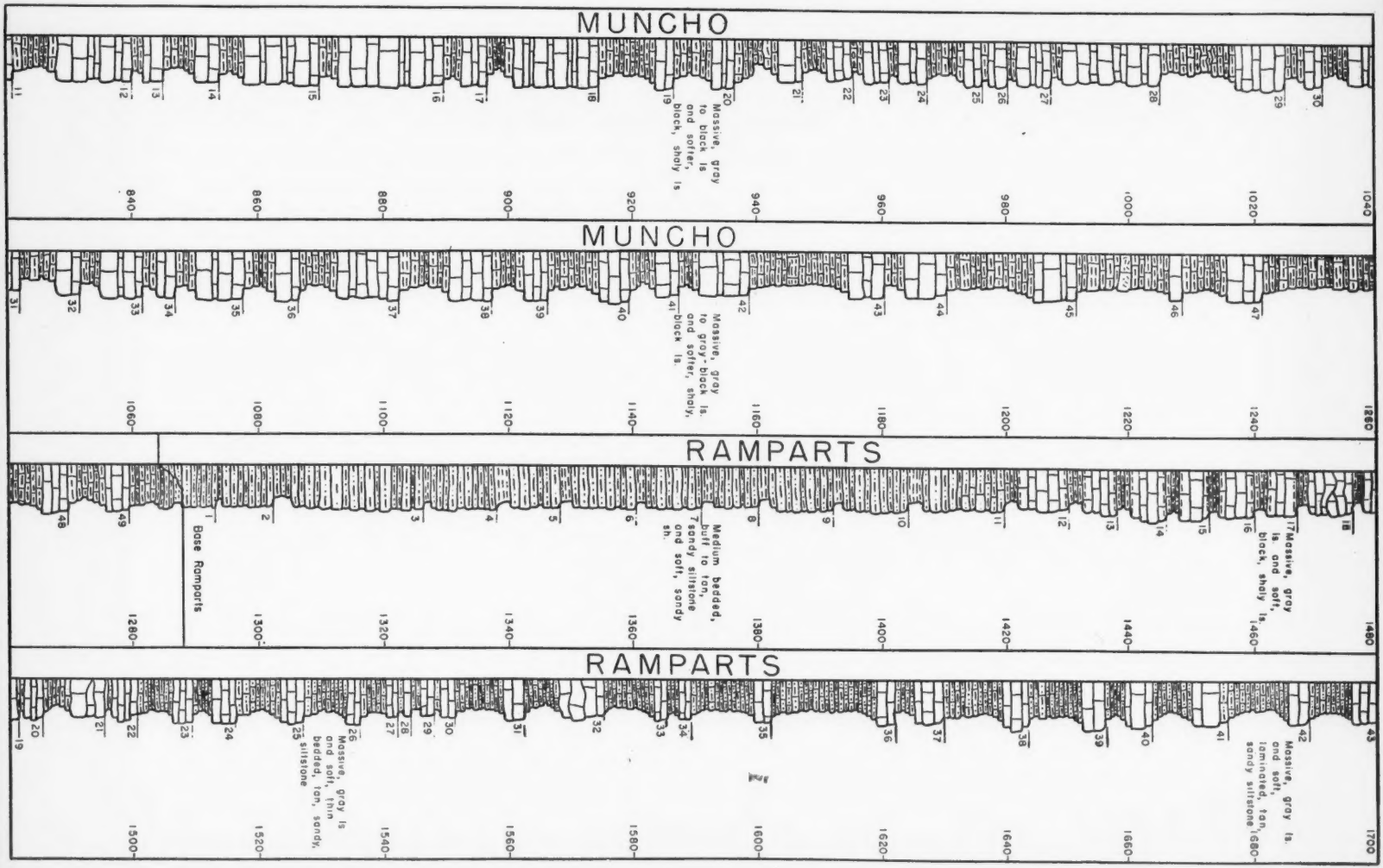

SILURIAN
MCCONNELL
MCCONNELL
MCCONNELL
MUNCHO
Cyclic, massive, gray, dolomitic ls. and black, carolinite ls.
Base DEVONIAN
Cyclic alternations of gray, massive, fine grained ls and dark gray to black, shaly ls.
Cyclic alternations of massive, gray, fine grained ls and dark gray to black, shaly ls
Cyclic alternations of massive, gray, fine grained ls and dark gray to black, shaly ls
Cyathophylloid coral zone
Laminated, sandy ls.
Rhythmically alternating gray, massive ls. and black, thinner bedded, shaly ls
Dark gray, irregularly bedded, porous, dolomite
Gray, chunky, porous, poorly bedded ls
Medium bedded, black, slightly shaly ls.

Text Figure 6a McConnell, Muncho, and Ramparts Formations, Trout River Valley, Mile 472, Alaska Highway.

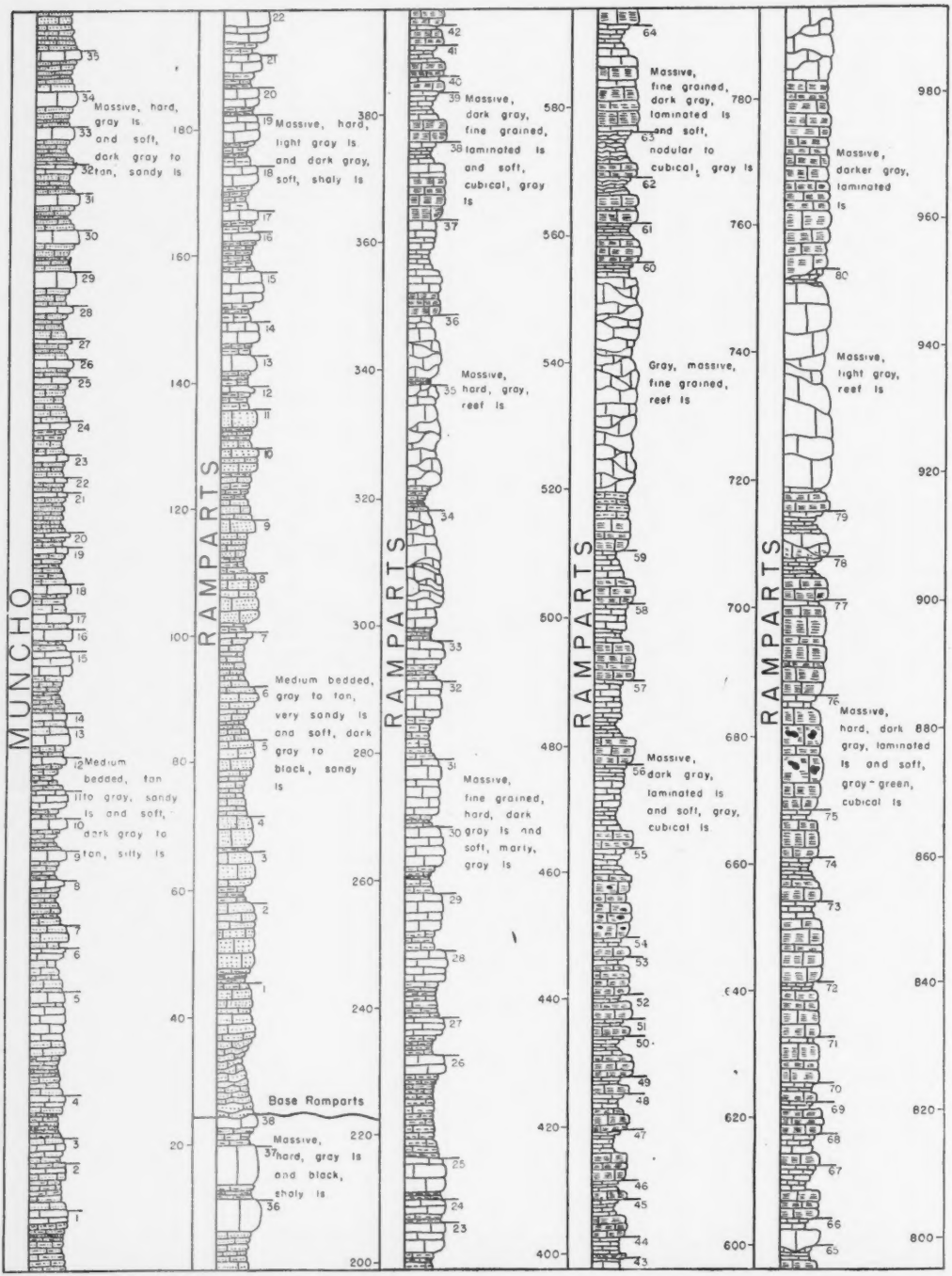
Text Figure 6b McConnell, Muncho, and Ramparts, Trout River Valley, Mile 472, Alaska Highway

Text Figure 6a McConnell, Muncho, and Ramparts Formations, Trout River Valley, Mile 472, Alaska Highway.

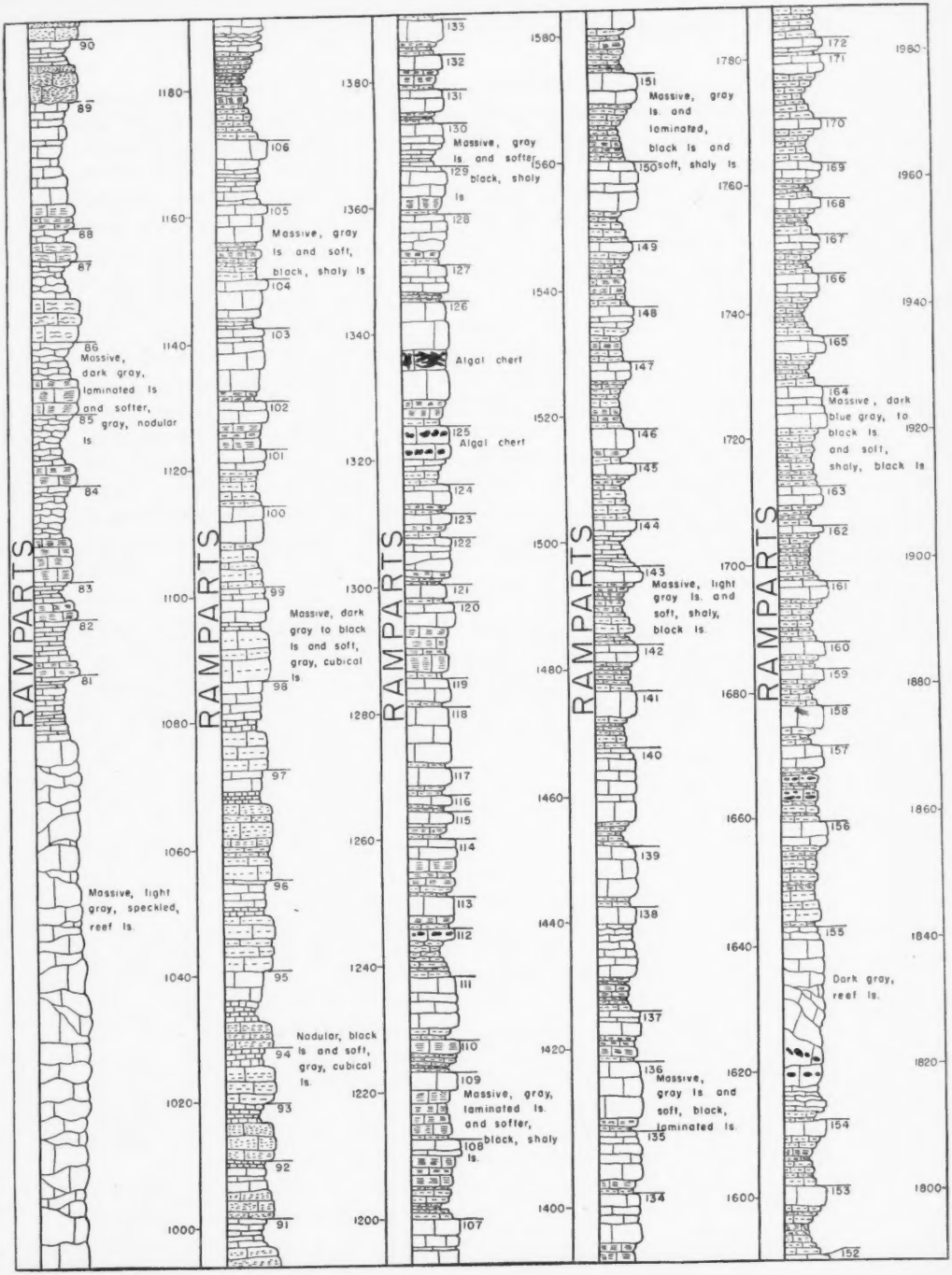
Text Figure 6b McConnell, Muncho, and Ramparts, Trout River Valley, Mile 472, Alaska Highway


MUNCHO
Massive, gray to black ls and softer, shaly ls
MUNCHO
Massive, gray to gray, black ls. and softer, shaly, black ls.
RAMPARTS
Base Ramparts
Medium bedded, buff to tan, sandy siltstone and soft, sandy sh.
Massive, gray ls. and soft, black, shaly ls.
RAMPARTS
Massive, gray and soft, fine bedded, tan, sandy siltstone
Massive, gray ls. and soft, laminated, tan, sandy siltstone

Text Figure 7a Muncho and Ramparts Formations, Toad River Valley, Mile 433, Alaska Highway


MUNCHO
RAMPARTS
RAMPARTS
RAMPARTS
RAMPARTS
Massive, hard, gray ls and soft, dark gray to tan, sandy ls
Medium bedded, tan to gray, sandy ls and soft, dark gray to tan, silty ls
Massive, hard, light gray ls and dark gray, soft, shaly ls
Medium bedded, gray to tan, very sandy ls and soft, dark gray to black, sandy ls
Base Ramparts
Massive, hard, gray ls and black, shaly ls
Massive, dark gray, fine grained, laminated ls and soft, cubical, gray ls
Massive, hard, gray, reef ls
Massive, fine grained, hard, dark gray ls and soft, marly, gray ls
Massive, fine grained, dark gray, laminated ls and soft, nodular to cubical, gray ls
Gray, massive, fine grained, reef ls
Massive, dark gray, laminated ls and soft, gray, cubical ls
Massive, darker gray, laminated ls
Massive, light gray, reef ls
Massive, hard, dark gray, laminated ls and soft, gray-green, cubical ls

Text Figure 7b Ramparts Formation, Toad River Valley, Mile 433, Alaska Highway.


RAMPARTS
RAMPARTS
RAMPARTS
RAMPARTS
RAMPARTS
Massive, light gray, speckled, reef ls.
Massive, dark gray, laminated ls and softer, gray, nodular ls
Massive, gray ls and soft, black, shaly ls
Massive, dark gray to black ls and soft, gray, cubical ls.
Nodular, black ls and soft, gray, cubical ls.
Massive, gray ls and softer, black, shaly ls
Algal chert
Algal chert
Massive, gray, laminated ls. and softer, black, shaly ls.
Massive, gray ls. and laminated, black ls and soft, shaly ls
Massive, light gray ls. and soft, shaly, black ls.
Massive, gray ls. and soft, black, laminated ls.
Massive, dark blue gray, to black ls. and soft, shaly, black ls
Dark gray, reef ls.

peak on which are the described sections of the Ronning, McConnell, and Muncho. A thrust fault lies in the saddle between this peak and the next ridge on the east, so that a continuous section into the upper part of the Ramparts could not be obtained.

As previously mentioned, the contact of the Ramparts formation with the Muncho is sharply unconformable. No basal conglomerate is present here; basal siltstones, however, have been somewhat oxidized. The lowest beds consist of gray, soft, siltstones which weather to a conspicuous tan or yellow color, making them readily recognizable even at considerable distances. The lower 130 feet of the formation are mostly of these beds, but they gradually decrease in proportion to the more massive, calcareous strata which become more typical of the Ramparts upward in the section. In the upper part, light gray, pure limestone, alternate with relatively massive, shaly to sandy, impure limestones, the more common dark limestone beds not being present. Many of the impure limestones are distinctly laminated and contrast sharply with the soft, pure limestone with which they alternate.

No fossils were collected from this part of the formation, but its relation to fossiliferous Ramparts elsewhere in the area makes its assignment to Devonian age unquestionable.

TOAD RIVER SECTIONS

From mile 430 to mile 443, the Alaska Highway follows the canyon cut through the Sentinel Range by the Toad River. Pre-Cambrian strata are exposed along the lower canyon walls in most of this area, with peaks generally capped by Ramparts limestone. Silurian beds are considerably deformed and faulted, but it was possible to study fairly complete Devonian sections at several localities along the river.

Several incomplete sections of pre-Ramparts beds were observed in this area, but detailed studies of these could not be made because of time limitations.

Ramparts formation.—One virtually complete Ramparts section is exposed on the east canyon wall and succeeding mountain peak above a small tributary that enters Toad River from the north at mile 433 (Figs. 7a and 7b).

The upper part of the Muncho formation is exposed along the lower valley walls. On it the Ramparts formation rests unconformably, with a few feet of erosional relief at the contact. The lithologic change from typical gray and black Muncho limestones to soft, tan, silty Ramparts beds is abrupt and conspicuous. Here, as in the Trout River section, slightly more than 100 feet of the base of the Ramparts weathers to a yellow and tan zone, conspicuous in the otherwise gray limestone section. This basal member consists of alternations of soft, brown, calcareous sandstone beds, with harder, more massive, brown, silty limestones. Forty repetitions of the sequence are present. The entire formation gradually becomes more calcareous upward, and finally becomes entirely limestone.

Above the tan basal zone, the first completely limestone cycles consist of alternations of black, shaly beds with dark gray, massive, relatively pure layers.

A very diagnostic reef-like limestone bed makes its appearance in the light unit of cycle 72. This limestone, gray, massive, and poorly bedded, is marked by a strangely speckled appearance caused by an abundance of tiny, cylindrical, unoriented granules of white calcite imbedded in the gray matrix. Such speckled limestone masses are also present in cycles 73, 74, 75, 98, 119, and 120. Similar beds form the dominant part of the Ramparts formation in the Summit Lake area.

In the lighter unit of cycle 119, a definite bioherm-like structure is locally developed. It is lenticular and relatively unstratified. At the thickest point observed, it measures approximately 100 feet in thickness, while laterally it is essentially absent in $\frac{1}{2}$ mile. The beds dip steeply on the flanks of this structure.

The darker units in cycles occupying the middle part of the Ramparts formation consist of relatively massive, black to dark gray, locally delicately laminated limestones. Normally they are softer because of their greater proportion of shale, and consequently occupy retreating parts of the exposures. In parts of the section, the black beds appear to be harder than the purer, gray units, and form the protruding beds of the cliff face. Such anomalous units first appear in cycle 74, and are present through most of the upper part of the section. In the top beds, the pure limestone units are harder, and laminated beds weather to retreating slopes. Above cycle 175 the laminated beds occur only as thin, shaly parting beds in the central part of each black unit.

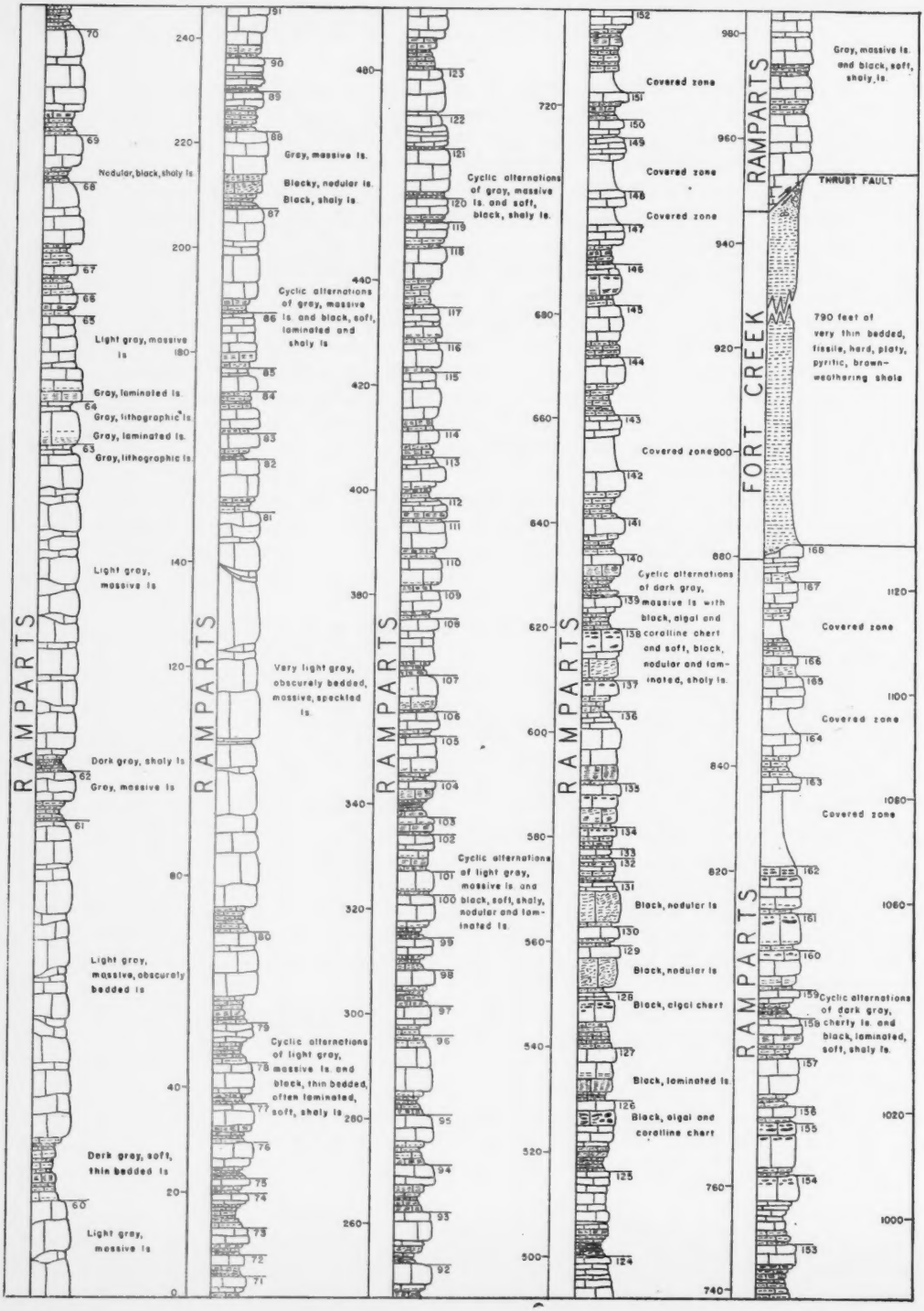
The light limestone of cycles 76 to 121 consists of relatively soft, very fine-grained, gray to greenish gray, cubically fracturing beds. In this series, exceptionally massive, light gray, speckled limestones occur in cycles 98, 118, 119, and 120. In each of these cycles, speckled limestone beds are found between laminated black beds, and cubically weathering light limestone units.

Jet black limestone, massive to shaly, and in some places nodular, appears in the dark units of cycles 127, 128, 129, 130, 132, and 134. Above cycle 129, the lighter unit reverts from massive limestone to the normal soft cubically weathering limestone similar to that of the lower cycles. In cycles 133, 134, 135, 136, and 137, the addition of a massive gray limestone bed, between the gray, soft bed, and the black shaly unit, is apparent. It occupies the same position as the previously described speckled gray beds. Above cycle 137, this gray, massive limestone replaces the soft layers of the lower cycles, and the normal relationship of soft, shaly, dark units and hard, projecting, light units, is present to the top of the section.

Because the light gray units in the upper part of the Ramparts are relatively dark, and contrast strikingly with the white, speckled limestones near the middle of the formation, it was found convenient in field work to refer to the middle member as the "White Ramparts" and to the upper as the "Dark Ramparts." Exposures of dark units are made exceptionally conspicuous in the upper part of the "Dark Ramparts" by their sharply retreating exposure.

Ramparts and Fort Creek formations.—The Ramparts-Fort Creek contact is

Text Figure 8, Ramparts and Ft. Creek Formations, Toad River Valley, Mile 430, Alaska Highway.


RAMPARTS
Light gray, massive ls
Gray, laminated ls.
Gray, lithographic ls.
Gray, laminated ls.
Gray, lithographic ls.
Light gray, massive ls
Dark gray, shaly ls
Gray, massive ls
Light gray, massive, obscurely bedded ls
Dark gray, soft, thin bedded ls
Light gray, massive ls
Nodular, black, shaly ls.
RAMPARTS
Gray, massive ls.
Blocky, nodular ls.
Black, shaly ls.
Cyclic alternations of gray, massive ls. and black, soft, laminated and shaly ls.
Very light gray, obscurely bedded, massive, speckled ls.
Cyclic alternations of light gray, massive ls. and black, thin bedded, often laminated, soft, shaly ls.
RAMPARTS
Cyclic alternations of gray, massive ls. and soft, black, shaly ls.
Cyclic alternations of light gray, massive ls. and black, soft, shaly, nodular and laminated ls.
RAMPARTS
Covered zone
Covered zone
Covered zone
Covered zone
Cyclic alternations of dark gray, massive ls with black, algal and coralline chert and soft, black, nodular and laminated, shaly ls.
Black, nodular ls
Black, nodular ls
Black, algal chert
Black, laminated ls.
Black, algal and coralline chert
RAMPARTS
FORT CREEK
Gray, massive ls. and black, soft, shaly ls.
THRUST FAULT
790 feet of very thin bedded, fissile, hard, platy, pyritic, brown-weathering shale
Covered zone
Covered zone
Covered zone
Cyclic alternations of dark gray, cherty ls. and black, laminated, soft, shaly ls.

not exposed in the section described at mile 433, but is excellently exposed on the conspicuous limestone peak north of Toad River opposite mile 430. This is the easternmost peak of the Sentinel Range north of Toad River. Pre-Silurian limestones at the base of the thrust block form the lower slopes of the mountain, and the Paleozoic sequence is well exposed to the top of the Fort Creek shale, where it is interrupted by a second thrust fault. The thrust block, of complexly folded Ramparts limestone, forms the peak. An excellent, fossiliferous section, including most of the Ramparts and Fort Creek formations, was located and measured on the lower eastern face of this peak (Fig. 8).

In general appearance, this Ramparts section closely parallels the one measured near mile 433. Massive, speckled, light gray limestone beds occur in the light units of cycles 100, 101, 103, 110, 118, and 119. Nodular black limestones are much more common in this section, the first occurring in cycle 126, with further intermittent occurrence upward through cycle 176. Their vertical extent is much more limited in the western section, where they appeared in cycle 127, and disappeared in cycle 133.

Chert also occurs more abundantly at mile 430, and fossils are much more common in the upper part of the section. Excellent faunas were collected in the Ramparts formation, from beds in and above cycle 192.

It has been found possible to correlate several individual cycles in this series with those of the section at mile 430. Since this section shows clearly that approximately the same number of cycles is represented in each area, correlative cycles have been assigned the same cycle numbers in the two sections. The two most obviously equivalent cycles are 126, in which striking chert deposits are present, and 81, which in both sections shows the same peculiarly speckled limestone. In the absence of any evidence to the contrary, it seems logical to infer that intervening cycles are correlative, although there are distinct differences in the lithologic facies of several of the units thus correlated.

Typical black Fort Creek shale rests on the sharply unconformable surface of cycle 168 of the Ramparts formation. Since 172 cycles are present in the western section, it seems logical to infer that considerable relief was present on the Ramparts surface before deposition of the Fort Creek beds.

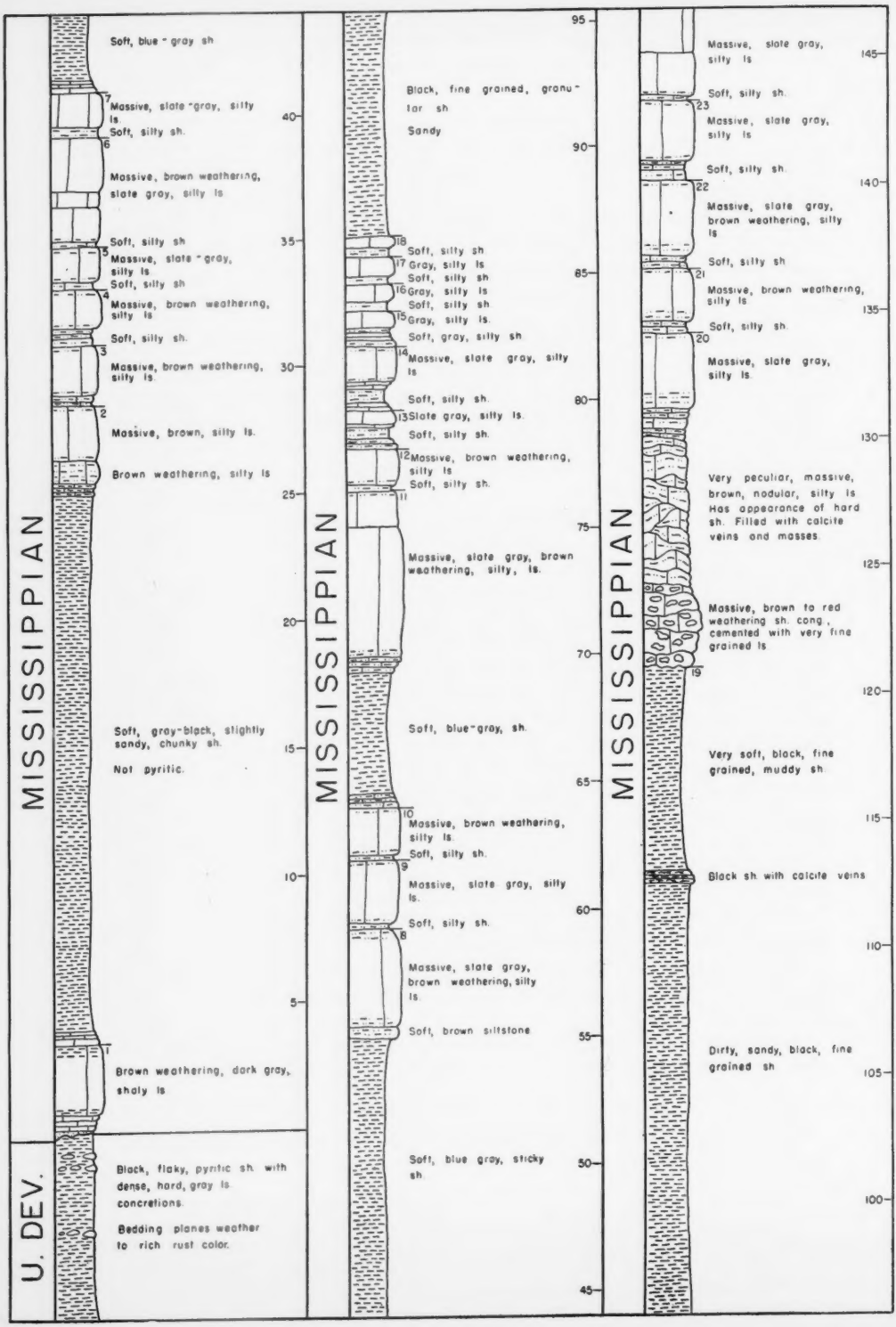
The Fort Creek formation here consists of thin-bedded, hard, fissile, pyritic, black shale which weathers to a yellowish and rust-brown color. The upper part of the section is sharply distorted and cut off by a second major thrust fault, so that the thickness of the formation, approximately 790 feet, is probably of no significance.

Because no evidence of cyclic deposition was apparent in the black Fort Creek beds, no attempt was made to study the details of their stratification.

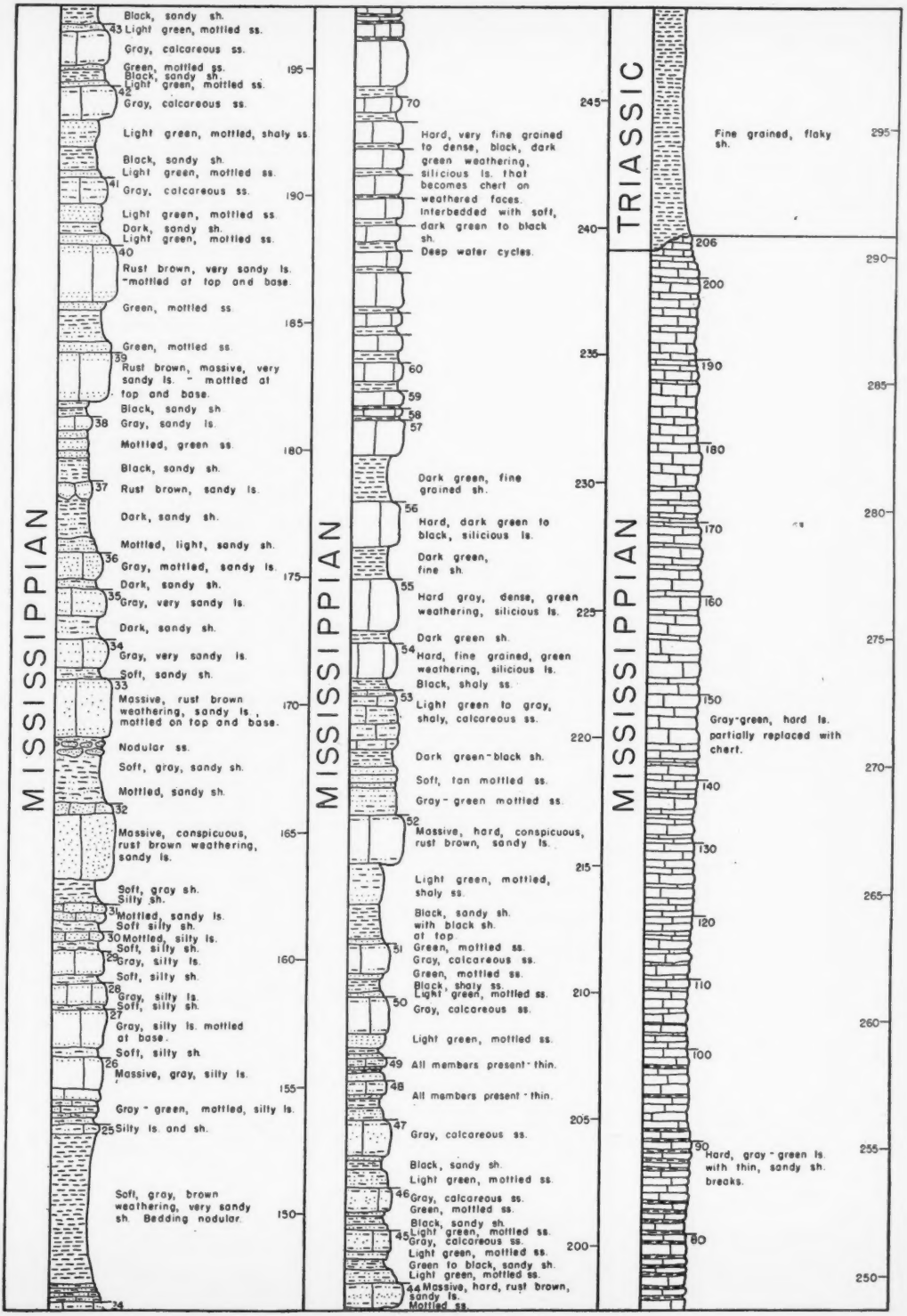
RACING RIVER SECTION

The Racing River Valley is a broad synclinorium. It forms a well defined topographic valley in the area of the Alaska Highway between the harder Paleo-

Text Figure 9a Type Section Kindle Formation, Mile 428, Alaska Highway.



Text Figure 9b, Type Section Kindle Formation, Mile 428, Alaska Highway.



zoic limestones of the Sentinel Range and Stone Range. The eastern edge of the Sentinel Range, crossed by the highway near mile 429, is marked by an imposing mountain front, where older Paleozoic rocks have been thrust over the younger, softer Paleozoic and Mesozoic series of the synclinorium. The eastern side of the structural valley is terminated along the dip slope of the older Paleozoic limestones which rise abruptly in another thrust-faulted area to form the Stone Range.

Mississippian rocks are exposed extensively in the Racing River synclinorium. One of the better and more complete exposures was located near mile 428 on the Alaska Highway, and is designated by the writers as the type section of the Kindle formation. The Kindle rests unconformably on the Fort Creek shale, and is overlain by beds of ammonite-bearing Triassic shaly limestones (Figs. 9a and 9b).

Cyclic sedimentation is well developed throughout the Kindle formation. In addition to the many simple cycles, there are suggestions of a larger rhythm, perhaps comparable with the megacycles found in the Pennsylvanian system in the United States. The dark units in cycles 2, 8, 11, and 19 consist of exceptionally thick beds of silty black shale. These thick accumulations of clastic material are separated by normal cyclic rhythms in which the dark units are comparatively thin.

Generally, the most common cycle in the lower member of the formation consists of thin, black, silty shale, overlain by relatively thicker, fossiliferous, gray, calcareous siltstone. In the lower beds of the section, similar fossils are found in both units of the cycles. There is no evidence of cyclic deposition for 10 feet above the top of cycle 19, but above this interval the section regains its normal cyclic nature. Although somewhat thinner than previous marker beds, the dark, shaly unit of cycle 25 seems to represent the top of another megacycle. Above this, the dark units thicken, and evidence of megacycles, if formerly present, entirely disappears.

Above cycle 20 a new element gradually becomes more prominent in each cycle. The shaly, dark unit is gradually replaced upward by peculiarly speckled green and gray sandstone bed. This grades into the gray, calcareous, light unit. The mottled beds first appear in either the upper or lower zones of the massive light limestone unit of the cycle. Higher in the section, from cycle 37 to cycle 53, a definite sandstone appears above and below each of the massive gray limestones.

Above cycle 54, the shaly unit of each cycle gradually diminishes in relative thickness, and the massive unit becomes more important. From cycle 69 upward, the dark unit is represented only by a bedding break, and the light unit by thin, cherty, limestones. This upper series has normal non-cyclic appearance of many Paleozoic formations in the Mississippi Valley.

STONE RANGE AREA

Early and Middle Paleozoic rocks are at the surface in the MacDonald Creek and Summit Lake areas, where they strike N. 20° W. These rocks, consisting

mostly of dense, massive, limestones, have been thrust eastward over the Upper Paleozoic and Lower Mesozoic beds of the region. They are relatively flat and show only minor folding and faulting except in the vicinity of the major thrust fault zones. In this area, extensive fault blocks rise abruptly from the lower, younger rocks on either side, into a barren series of conspicuous gray limestone peaks. Excellent sections are exposed, but in many localities a heavy talus cover makes measurement and observation of the bed rock impossible.

Of the two mountainous limestone areas, the Stone Range clearly was closer to the shore line and source of sediments, at least during Lower and Middle Paleozoic time. This is evidenced by the high proportion of clastic materials in the section. Many of the beds are definitely cyclic in this area, but through considerable thicknesses the cyclic nature, if present, is much obscured by evidences of more unsettled, near-shore conditions.

The following sections are within 5 miles of each other and together form a clear picture of the Paleozoic sequence in the Stone Range.

SUMMIT LAKE SECTION

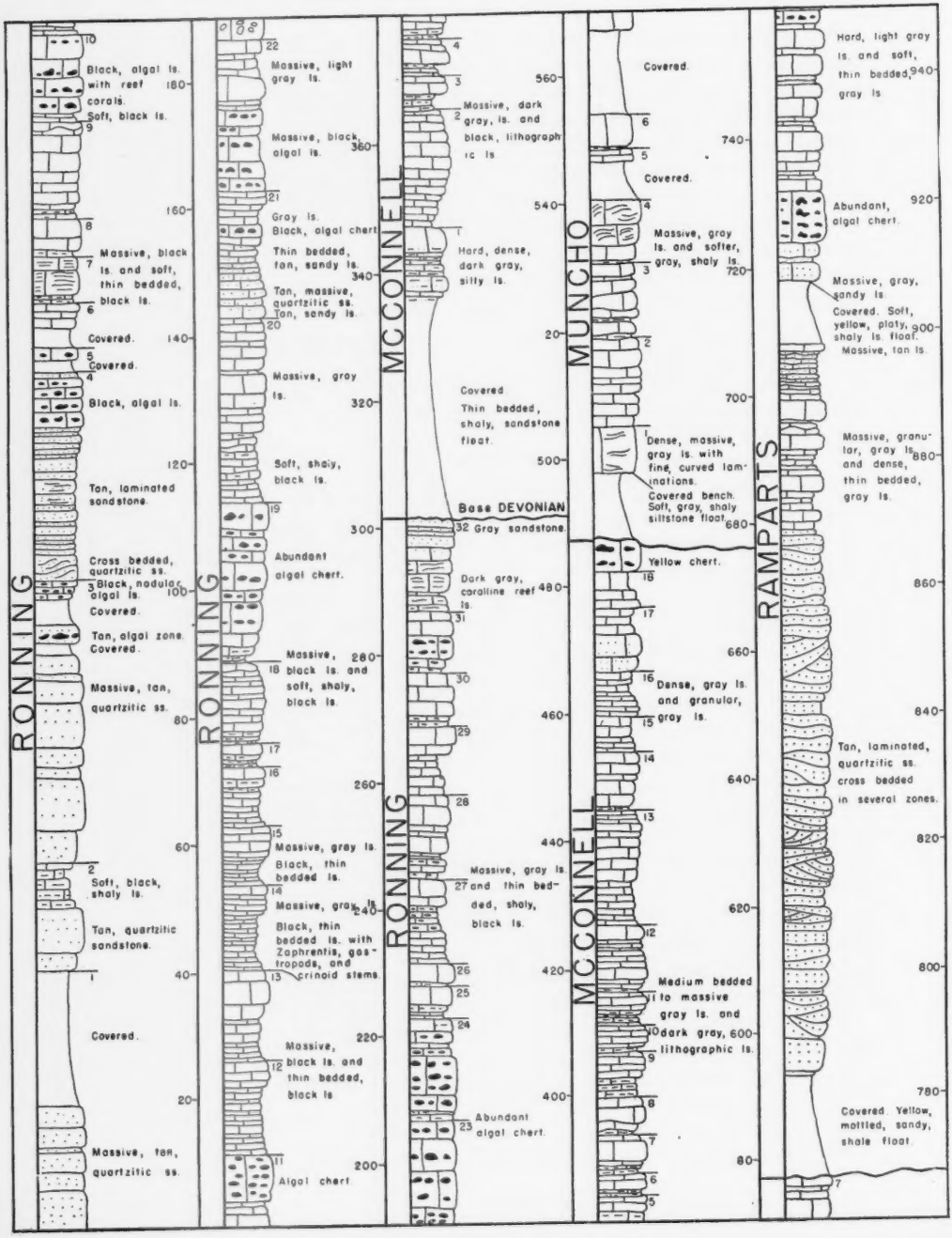
This section was measured on the southwest side of Mount St. Paul, north of the highway, 2 miles west of Summit Lake station. The lower part is covered by vegetation, the base of the column beginning at timberline, in the upper beds of the Ronning formation.

Ronning formation.—The lowest continuous outcrop of this formation consists of easily distinguishable cycles of massive, tan, quartzitic sandstone and black, shaly, impure limestone. The fourth discernible cycle appears to be transitional toward normal cyclic deposition, in which the darker units consist of black, shaly, fossiliferous limestone, and the light units of typical gray limestone. The latter unit, however, is not consistently gray in this area, but commonly contains considerable amounts of intercalated black shale (Figs. 10a and 10b).

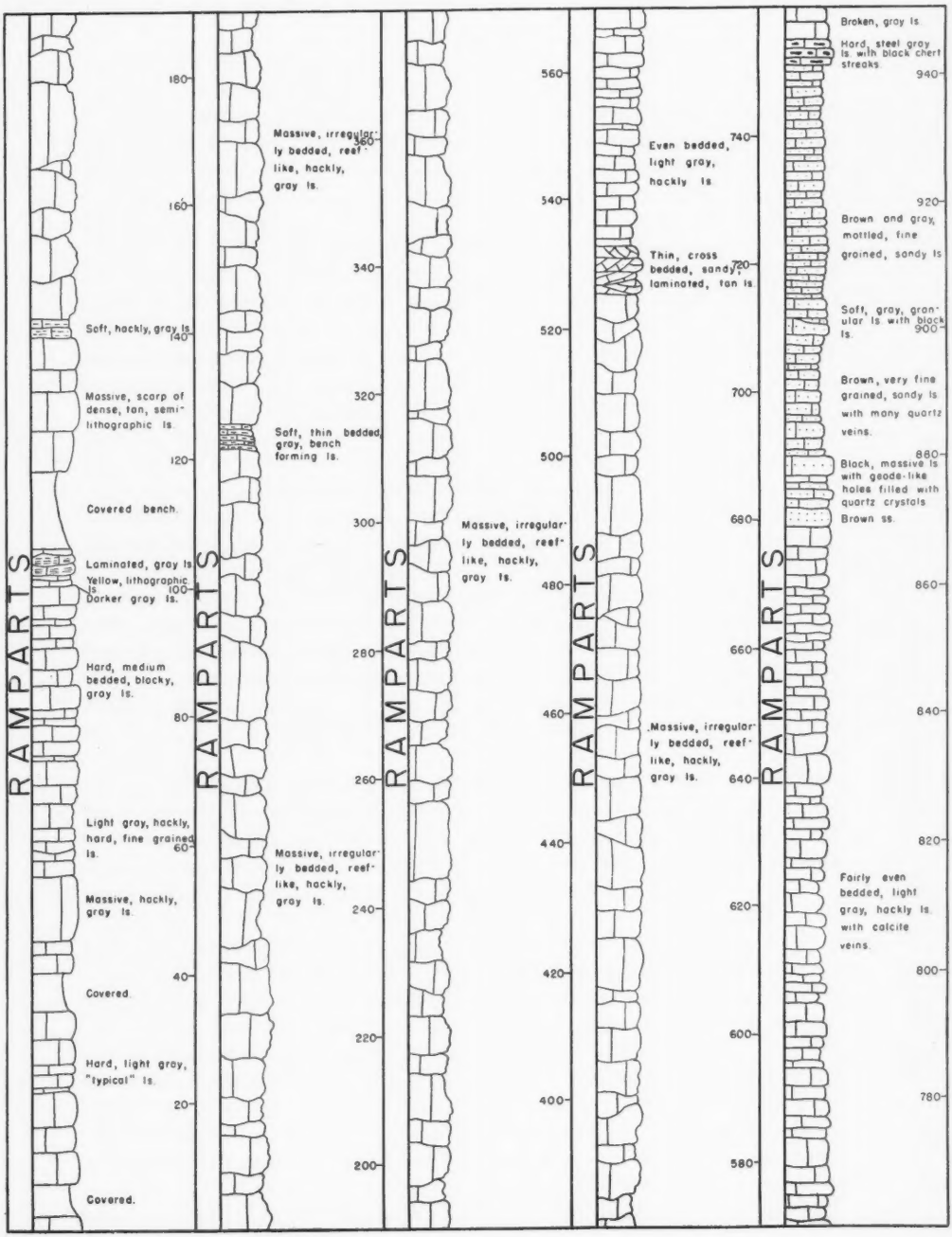
The maximum exposure of the Ronning formation in this section measures approximately 490 feet, in which 32 cycles can be recognized, while the section in the Sentinel Range contains 38 cycles in 1,190 feet. Such a wide discrepancy in total thickness may not in itself be significant, but the different average thicknesses of the cycles are tremendous, and leads one to the conclusion that, if they are at all equivalent, deposition in the Sentinel Range was much more rapid than in the Stone Range. In the latter section, the distinct erosional unconformity at the top of the formation suggests that a part of the complete sequence was probably removed before the deposition of the overlying McConnell formation.

McConnell formation.—This series of beds is also relatively thin in the Summit Lake area, consisting of only 185 feet of strata. Eighteen cycles can be recognized here, as compared with 51 in the Sentinel Range area. Lithologically most of the Summit Lake McConnell section is closely comparable with that of the Muncho Lake area, that is, practically the entire section consists of dense, fine-grained limestones alternating between shades of gray and black in each cycle. A

Text Figure 10a Silurian – Devonian Section Near Summit Lake, Mile 394, Alaska Highway.


RONNING
Black, algal ls. with reef corals.
Soft, black ls.
Massive, black ls. and soft, thin bedded, black ls.
Covered.
Covered.
Black, algal ls.
Tan, laminated sandstone.
Cross bedded, quartzitic ss.
Black, nodular algal ls.
Covered.
Tan, algal zone. Covered.
Massive, tan, quartzitic ss.
Soft, black, shaly ls.
Tan, quartzitic sandstone.
Covered.
Massive, tan, quartzitic ss.
RONNING
Massive, light gray ls.
Massive, black algal ls.
Gray ls. Black, algal chert
Thin bedded, tan, sandy ls.
Tan, massive, quartzitic ss.
Tan, sandy ls.
Massive, gray ls.
Soft, shaly, black ls.
Abundant algal chert.
Massive, black ls. and soft, shaly, black ls.
Massive, gray ls. Black, thin bedded ls.
Massive, gray ls. Black, thin bedded ls. with Zaphrentis, gastropods, and crinoid stems.
Massive, black ls. and thin bedded, black ls
Algal chert
McCONNELL
Massive, dark gray, ls. and black, lithographic ls
Hard, dense, dark gray, silty ls.
Covered Thin bedded, shaly, sandstone float.
Base DEVONIAN
Gray sandstone
Dark gray, coralline reef ls.
Massive, gray ls and thin bedded, shaly, black ls.
Abundant algal chert.
RONNING
MUNCHO
McCONNELL
Covered.
Covered.
Massive, gray ls. and softer, gray, shaly ls.
Dense, massive, gray ls. with fine, curved laminations.
Covered bench. Soft, gray, shaly siltstone float
Yellow chert.
Dense, gray ls. and granular, gray ls.
Medium bedded to massive gray ls. and dark gray, lithographic ls.
RAMPARTS
Hard, light gray ls. and soft, thin bedded, gray ls.
Abundant algal chert.
Massive, gray, sandy ls.
Covered. Soft, yellow, platy, shaly ls. float. Massive, tan ls.
Massive, granular, gray ls and dense, thin bedded, gray ls.
Tan, laminated, quartzitic ss. cross bedded in several zones.
Covered. Yellow, mottled, sandy, shale float.

Text Figure 10b Devonian Section Near Summit Lake, Mile 394, Alaska Highway



sandstone, overlain by a covered, probably shaly zone, occurs at the base. Thirty feet above the contact, the beds become cyclic, alternating between dark gray, slightly shaly limestone, and lighter gray, more massive beds of somewhat lower silt content. Small masses of yellow chert are abundant in the top bed.

It is not possible to determine whether a part of the McConnell formation is missing, or whether the formation merely thins eastward. If the McConnell transgressively overlaps the Silurian surface from the west, it is probable that part, if not most, of the lower beds of the formation are missing.

In this area the McConnell formation is unconformably overlain by the Muncho, and it is also possible that the top beds of the former have been cut off by erosion as the lower beds are missing by transgressive overlap. Probably both are responsible for some thinning of the formation in the Summit Lake area, together with the normal thinning which occurs in a formation as it is traced landward.

No fossils were found in the McConnell formation in the Summit Lake section, but lithologic correlation seems apparent, and stratigraphic position definitely determines the relative age of these beds.

Muncho formation.—Approximately 85 feet of limestone between the McConnell and Ramparts are classed with this formation, although fossil evidence is lacking here also. Along the mountain face at the base of this formation there is a conspicuous bench where the beds are lithologically different from both the underlying McConnell and the overlying Ramparts limestones. The three covered zones probably represent shales or at least very shaly zones in the limestone. The upper part of the formation consists of irregularly cyclic alternations of black, shaly limestone, and more massive, gray, relatively purer limestone.

This formation is unconformably overlain by the conspicuous massive sandstone scarp which marks the base of the Ramparts formation throughout the region.

Ramparts formation.—The tan to yellow, sandy beds at the base of the Ramparts in the Sentinel Range apparently become more sandy eastward, as the basal beds in this section are almost certainly sandstones, although mostly covered. As in the Sentinel Range, their conspicuous coloration sets them apart clearly from other beds in the section, and there is practically no chance of mis-correlation at this point.

Above the lowermost, largely concealed beds, a prominent, tan, rather coarse-grained and cross-bedded sandstone extends 90 feet. This sandstone grades into a series of easily differentiated gray and black limestone cycles. Most of the middle and upper beds of the Ramparts in the section consist of the same type of massive, white, speckled, limestone beds characteristic of the middle Ramparts in the Sentinel Range, particularly the reef-like, irregular masses in the Toad River sections.

The upper beds of the Ramparts are so covered with talus in this section that separation into distinct cycles is not possible. The general characteristics of the limestone can be determined, but lithologic details are obscure, frost action having produced a jumble of limestone blocks over most of the peak. Some beds

could be observed in place through the section, however, and permitted a fairly accurate measurement of the total thickness including a few feet of the upper, dark gray, cyclic limestone characteristic of the upper Ramparts formation in the Sentinel Range. The total thickness of the Ramparts in this section is slightly more than 1,100 feet.

MACDONALD CREEK SECTIONS

The Alaska Highway descends into MacDonald Creek Valley west of Summit Lake, paralleling the creek on its east side for several miles. MacDonald Creek originates in the high mountains south of the Summit Lake area, and turns abruptly northwest where the highway enters the valley. The section to be described was measured south of MacDonald Creek, on the peak directly opposite the junction of the highway with the valley (Fig. 11).

Pre-Silurian rocks exposed in this section are relatively horizontal, non-metamorphosed limestones which may be Cambrian in age. No fossils were observed, but generally the beds are similar in composition and general lithologic character to the pre-Silurian strata in the Sentinel Range, farther west.

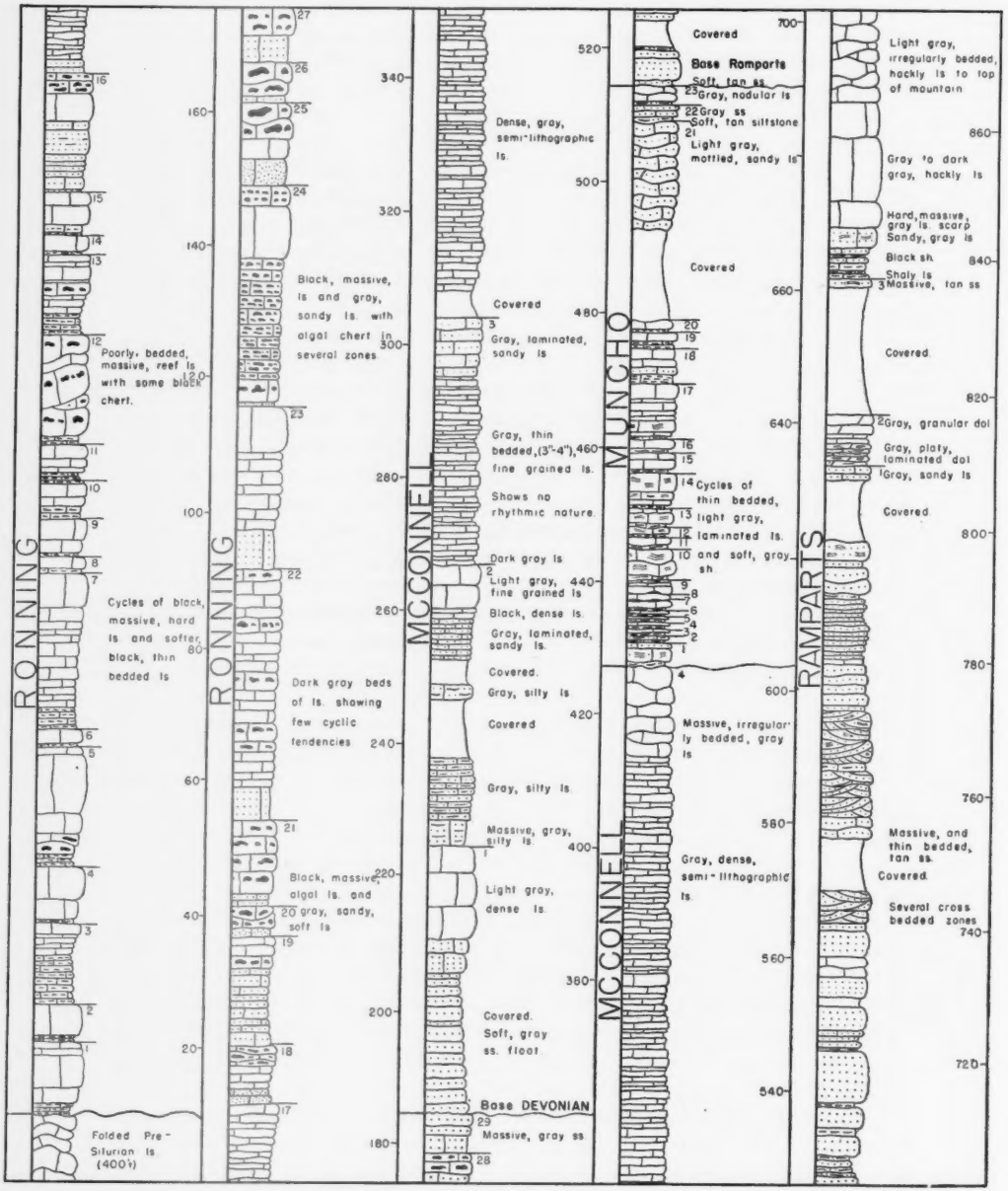
Ronning formation.—Cyclic sedimentation is almost as poorly developed in the Ronning formation as it is in the section across the valley on Mount St. Paul. Due apparently to the proximity of the shoreline, cycles are not so well developed as in other, more marine sections. Chert occurs in both units of the cycles, which have been recognized principally on color differences between black shaly limestone and gray purer limestone beds. In some places this definition was aided by the sandy zones in the more bituminous units. It is not possible to correlate all of the cycles successfully between this and the Mount St. Paul section, although the distance is relatively short. Conspicuous algal chert in cycles 23 and 24 on Mount St. Paul can be clearly seen in cycle 24 of this section. From the distinctive lithologic character and fauna of this one zone, correlation between the two beds seems apparent. With this datum plane as one of contemporaneity, a comparison of the remainder of the Ronning sections in the two adjoining areas shows that in approximately 75 feet there are 8 cycles in the Mount St. Paul section, corresponding with only 5 cycles in the 40 feet of the present section.

The base of the Ronning formation in the Stone Range also varies locally within wide limits. The lower beds on Mount St. Paul are much thicker than those of the other section, and also include a greater proportion of sandy beds. Over such a short distance this great change seems most likely to be explained by the presence of a sandy, irregular, pre-Silurian surface.

Typical Niagaran fossils occur in most of the chert-filled limestones of the Ronning formation. *Favosites favosus* (Goldfuss), *F. niagarensis* Hall, *Halysites catenulatus* (Linnaeus), *Heliolites megastoma* McCoy, and several cyathophylloid corals occur most abundantly.

McConnell formation.—Approximately 240 feet of strata are in the McConnell formation of the MacDonald Creek section. The contact is covered, but float indicates that soft, relatively fine-grained, gray sandstone probably forms the

Text Figure 11, Silurian, Devonian Section, South Side MacDonald Creek, Mile 396, Alaska Highway.



bed rock. Cyclic sedimentation is very poorly developed. The basal sand directly overlain by pure, gray limestone which forms the top of the only well developed cycle. This cycle is similar to the corresponding cycle of the Mount St. Paul section, across the valley. On Mount St. Paul, however, eighteen rather weakly differentiated cycles are present, whereas none could be recognized here, a fact which again illustrates that cycles in this area are variable locally.

Higher in the section, many thin, slightly nodular, semi-lithographic dark gray limestones are present. These beds include only two limestones that could be described as massive, and it appears that the cyclic nature of the formation is almost entirely lost.

Lithologically the McConnell formation of the Stone Range area bears little relationship to that developed in the Sentinel Range. In general, the formation is much thicker and more obviously cyclic in the Sentinel Range. Since no fossils have been found in the McConnell formation, correlation has been entirely on its stratigraphic position.

Muncho formation.—Approximately 95 feet of strata represent the Muncho formation in the MacDonald Creek section. The lower part consists of thin cycles of light gray, laminated and nodular limestone beds, and soft gray shales. The upper part is poorly exposed, but the few exposures are very sandy.

Similarities of this section with that of Mount St. Paul are more notable than was true of the lower part of the section. The lower part, of nodular limestones and shales, is similar in both sections.

The upper beds are poorly exposed, but the top layer is the same in both sections.

The Muncho formation is overlain unconformably by the Ramparts formation in this section.

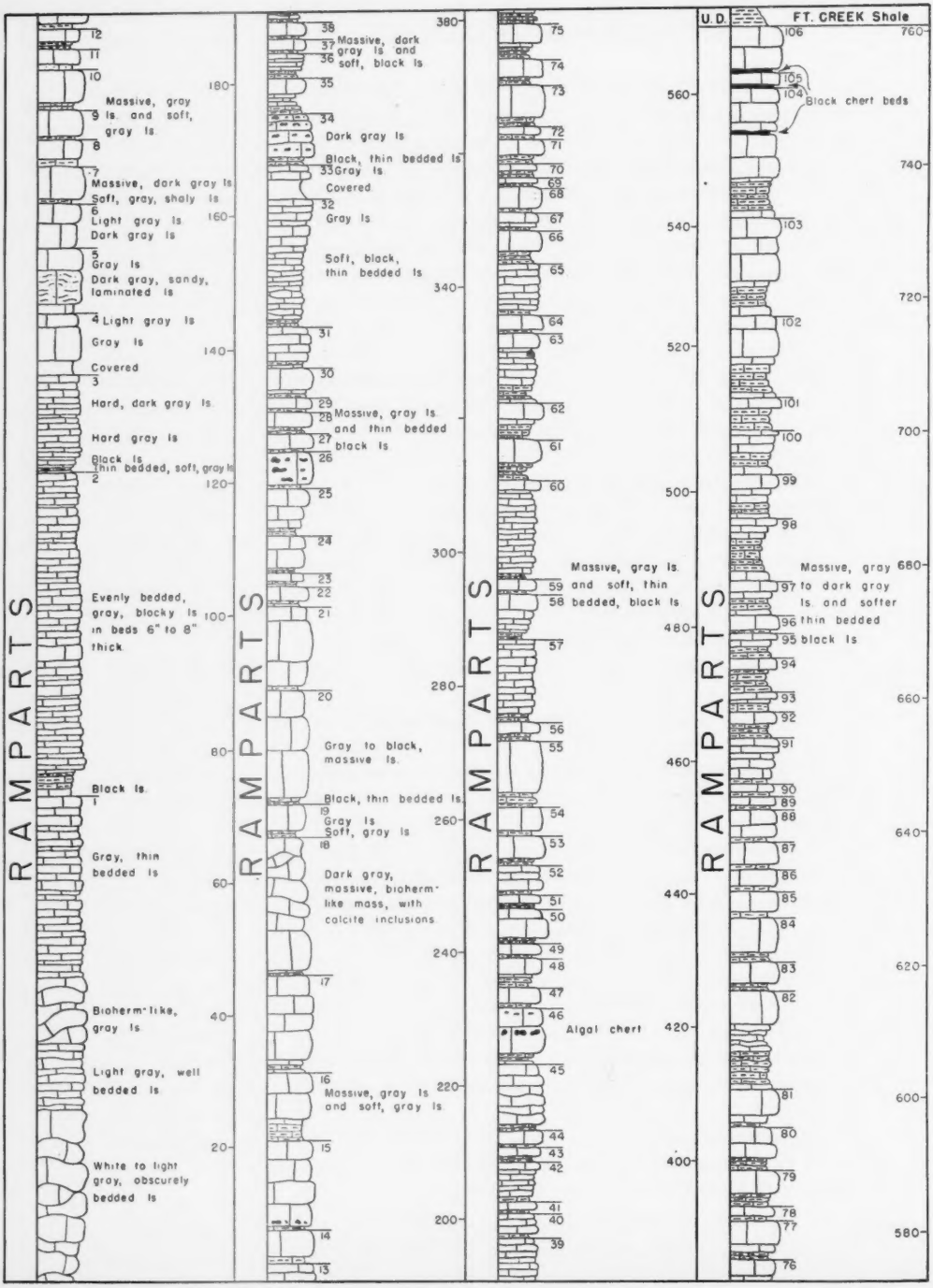
Ramparts formation.—Only the base of the Ramparts could be measured in the MacDonald Creek section, since the entire upper part is covered with large, irregular slump blocks.

The lower beds are similar to those on Mount St. Paul, consisting of massive, tan to yellow, cross-bedded, quartzitic sandstones, interbedded with tan to gray, soft shales. The sandy part of the Ramparts reaches a thickness of approximately 110 feet, slightly more than that of the Summit Lake section.

Upper Ramparts-Fort Creek contact.—An excellently exposed contact between these two formations was located by M. Y. Williams (1944, p. 16) in the bed of a small creek crossing the highway in mile 398. Fort Creek shales are well exposed along the creek bed for ¼ mile upstream from the highway. Since the beds dip steeply toward the highway and MacDonald Creek, practically the entire Ramparts section is exposed along the walls of the creek, upstream from its Fort Creek contact.

Measurement of beds was made from the top of the Ramparts formation down to the massive, speckled, white limestone beds previously noted near the summit of Mount St. Paul, 3 miles eastward.

Text Figure 12, Ramparts Formation, MacDonald Creek, Mile 398, Alaska Highway.



A combination of the three sections thus presents a fairly complete picture of the lower and middle Paleozoic sequence in the Stone Range (Fig. 12).

Ramparts formation.—Approximately 735 feet of massive limestone is present in the upper or "Dark Ramparts" section of the Stone Range. The entire member is cyclic, becoming much more regularly so in the uppermost beds, in which 106 complete cycles can be clearly recognized.

The lowermost measured beds consist of dark gray, very thinly bedded limestones alternating with black, shaly limestones. These strata are undoubtedly the same as those capping Mount St. Paul, but more poorly exposed there. Thirty-one regular alternations of massive, gray limestone and shaly, black limestone are present from the base of the upper dark member of the Ramparts to the Fort Creek contact. Upward, with the exception of the interval from cycle 44 to cycle 56, the section consists of relatively thicker, dark gray, thin-bedded limestones alternating regularly with thinner, considerably lighter gray strata.

In general, the cycles developed in this section are very similar to those observed in the Sentinel Range westward, contain somewhat more clastic material in both units of the cycles.

Fossils are abundant in the upper part of this section. Beds immediately below the Fort Creek contact are filled with corals. *Hexagonaria percarinata* Sloss, *Favosites* sp., and *Cladopora* sp. are the most common forms. *Hexagonaria* occurs very abundantly in the Ramparts formation of the lower Mackenzie River area, in the Traverse beds of Michigan, and in the Cedar Valley limestone of Iowa.

SUMMARY OF OBSERVATIONS CONCERNING CYCLIC SEDIMENTATION

Most of the Paleozoic and early Mesozoic sediments studied in the Alaska Highway area showed evidence of cyclic sedimentation. Present knowledge about cyclic sedimentation does not permit conclusive interpretation with regard to the environment of origin of the sediments involved in the cycles. The cycles are described in some detail in order to accumulate a backlog of information that may eventually lead to more satisfactory interpretation.

It may be valuable to present a possible interpretation about origin of the sediments involved where there is some evidence even though later studies may prove the interpretations erroneous. Certain observations about cyclic sediments were valuable as stratigraphic tools during the process of completing the field work. Most of these observations are not new but at least they are in part applied to a new portion of the stratigraphic column.

1. The cyclic sediments studied appear to have been best developed in the deeper parts of the sedimentary basin. The evidence for this observation can be demonstrated by a comparison of the cyclic sediments of the Sentinel Range with those of the Stone Range. Cycles were sharply defined and excellently developed in the Sentinel Range and poorly developed in the Stone Range. A marked increase in the amount of clastic material and a general thinning of the section in the Stone Range in the part of the column where the cycles were most poorly developed suggests this interpretation.

2. The most common type of cycle observed in the area consisted of a black, shaly, fossiliferous limestone unit followed by a more massive, relatively pure, gray, non-fossiliferous limestone unit. No evidence is available to prove that these cycles are in any way comparable with the type cycles as developed in Pennsylvanian sediments of the Mississippi Valley area. The cycles of the Alaska Highway area do not begin with non-marine conditions, proceed through marine submergence, and return to shore conditions. There seems to be no reason to assume that they were different, however, since it is unlikely that oscillation of a shoreline, whatever its cause, would not affect the deeper parts of the basins. It is as logical to assume that they would be developed in systems of rocks other than Pennsylvanian as to assume that they would not be developed.

If the assumption is made that the observed cycles represent sediments deposited in association with the influence of oscillation of sea-level, present knowledge does not even permit unquestioned assignment of deep-water and shallow-water units within the simple cycle. Generally accepted thought on the subject indicates that the fine shaly muds accumulate in stagnant, deeper water and that the pure limestones indicate more shallow-water, often near-shore conditions. There is some evidence in the sediments of the Alaska Highway area that suggests other interpretation. In the Summit Lake and MacDonald Creek sections, which because of increased percentages of clastic material have been interpreted to have been deposited closer to shorelines, gray, massive, pure limestone units are poorly developed in the cycles. There is a possibility that in wide shallow basins of sedimentation, particularly where the topography of the adjacent landmass is subdued, the zones of fine, shaly mud contamination might lie relatively close to the shore and that pure limestones could be deposited farther out in the shallow basin. In this case the black silty units of the cycles would be interpreted as shallow-water in origin. In the Alaska Highway area, it was found that the quartz-sand beds were much better developed in association with the black, shaly units than with the limestone units.

3. Lithologic units within cycles have been found to change vertically, gradually within formations. The only observation that might help interpret the origin of such changes is the fact that additions and subtractions of lithologic units are associated more closely with the black, shaly units than with the pure, gray limestone units.

4. Some evidence which suggests the presence of larger cyclic rhythms somewhat comparable with the megacycle (Moore, 1935, p. 29) has been accumulated in connection with studies of Mississippian rocks. The lower part of the Mississippian section consists of sequences of well developed cycles that consist of thin shaly zones followed by more massive, gray, calcareous siltstone beds. Each of these sequences of cycles is followed by relatively thick shale beds such are developed in the base of cycles 2, 8, 11, 19, and 25 (Figs. 9a and 9b).

Subsequent studies of Mississippian rocks in Montana and southern British Columbia during the summers of 1947 and 1948 have demonstrated remarkable development of megacyclic sedimentation.

5. Fossils were found in much greater abundance in the black, shaly units than in the pure, massive, gray limestone units. It was not possible to check this observation thoroughly due to the relatively nonfossiliferous nature of most of the Devonian sediments in the area. Most of the fossils in the Silurian, Ronning formation, were limited to the black, shaly units. The occurrence of fossils abundantly in black shaly units is not consistent with the interpretation that the black, shaly units represent the stagnant, deeper-water sediments.

6. Some evidence exists suggesting that it may be possible to determine deepening or shallowing of a sedimentary basin by a study of successive cycles. The Mississippian section offers the most evidence and it is possible that the interpretation offered is erroneous. The lower cycles in the Mississippian section are thick due to excess amounts of clastic sediment. The amount of clastic material in the rocks gradually diminishes upward in the section until above cycle 99 nothing but thin shaly partings separate the limestone beds. The interpretation of this section suggests that these sediments were deposited in a gradually deepening basin with the source of clastic sediments gradually becoming more remote. The interpretation would be exactly opposite if it were assumed that the black silty shales accumulate only in deep water. The writer's interpretation also shows beds that would commonly be interpreted as normal non-cyclic beds in the Mississippi Valley area as representing thinly developed cycles (cycles 99–206). They appear as a normal thin-bedded limestone with thin shale partings. The only evidence for considering that they are cyclic consists of the gradual diminishing in thickness of known cycles grading imperceptibly into these limestone beds with shale partings. It is not suggested that all normal limestone beds with shale partings such as these are cyclic but the writers draw attention to this occurrence. Careful reexamination of some of the common so-called non-cyclic beds in the Mississippi Valley area may throw more light on this subject.

7. In general, unconformable surfaces can sometimes be predicted from considerable distances below the contact due to the fact that cyclic sedimentation seems to not be developed in these very shallow, near-shore, strand-line sediments. Such an accumulation of sediments can be seen in the top of the McConnell formation in the Trout River Valley section (Fig. 6a). Unconformable surfaces can be predicted from above the contact only by the increase in clastic sediment such as seen in the base of the Ramparts formation or in the base of the Ronning formation in the Summit Lake area.

8. Cyclic sedimentation seems to re-establish itself more quickly above unconformable surfaces than below them. This is due to the greater relief ordinarily present on landmasses. Different rock units due to depth changes can be developed much more quickly on submerging shorelines of considerable relief than on the flat-shoaling emerging sea floor. The contact between the McConnell and Muncho formations exhibits this condition excellently.

9. Absence of non-cyclic material in the top of a formation may indicate extensive erosion. The beds of the Ronning formation (Trout River Valley section) are cyclic up to the unconformable contact which indicates removal of the normal

non-cyclic upper beds. The same condition exists on all observed Mississippian Triassic contacts.

10. Cycles can be used for detailed correlation at least over short distances. It is even probable that cycle thickness patterns might be used for correlation in the same manner as varved clays. Transgressive overlap on unconformable surfaces can be demonstrated by counting cycles above a known bed that has been correlated with certainty. In the Ronning formation as developed at Summit Lake 8 cycles occur above cycle 24 and in the MacDonald Creek section only 5 are present above cycle 24.

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TERTIARY FORMATIONS OF PANAMA CANAL ZONE AND ADJOINING PARTS OF PANAMA[1]

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ABSTRACT

The Tertiary formations of the Canal Zone and adjoining parts of Panama range in age from late Eocene to late Miocene, or possibly early Pliocene. New formation and member names—Gatuncillo formation, Quebrancha limestone member of Caimito formation, La Boca formation, and Pedro Miguel agglomerate—proposed in official Panama Canal reports are defined.

Fossils from Vamos Vamos, a submerged locality in the Gatun Lake area, are considered early Oligocene in age. The fossiliferous strata at that locality are inferred to represent a marine tongue in the essentially non-marine Bohio formation.

The late Eocene Gatuncillo formation is strongly transgressive; the middle and late(?) Miocene Gatun formation is also transgressive; the late Oligocene(?) and early Miocene Culebra formation and the late Miocene or early Pliocene(?) Chagres sandstone represent minor overlaps.

INTRODUCTION

Geological studies dealing directly or indirectly with the stratigraphy and paleontology of the Tertiary formations along and near the Panama Canal have been made over a span of many years. They may be grouped in three main periods corresponding, respectively, with French operations, American construction, and studies during recent years by the Geological Section of the Special Engineering Division of The Panama Canal.

The French investigations were summarized by Bertrand and Zürcher (1899), whose report was preceded by Hill's (1898). A year after American operations were started in 1905, Ernest Howe was engaged by the Isthmian Canal Commission. Though Howe was in the Canal Zone only a few months, he outlined the essential features of the stratigraphy (Howe, 1907, 1908). Much information was assembled by D. F. MacDonald, who was resident geologist of the Commission from 1911 to 1913. During that period many collections of fossils were made, particularly in the latter part of 1911, when T. W. Vaughan, of the United States Geological Survey, collaborated with MacDonald. These collections are particularly valuable, as many of the fossil localities were later inundated by the Canal, Gatun Lake, and Madden Lake. They were the basis for *Bulletin 103* of the United States National Museum, which was prepared under the direction of Vaughan and is the most comprehensive publication on Canal Zone paleontology (Vaughan, 1919). That publication also contains a stratigraphic summary by MacDonald (1919). MacDonald had planned to include more detailed information in a report on the geology of Panama, which was partly prepared but never completed. The Geological Section of the Special Engineering Division was organized in 1938.

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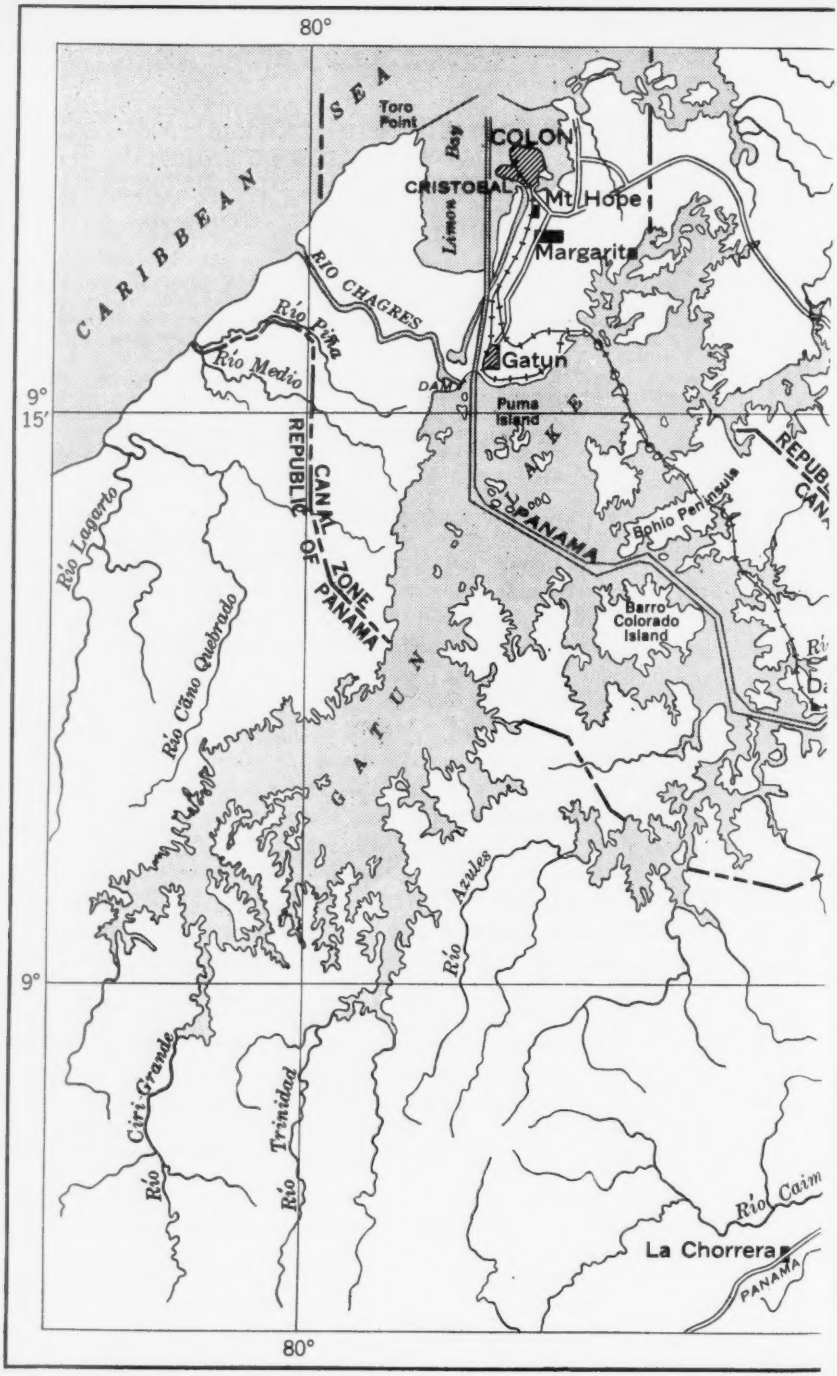
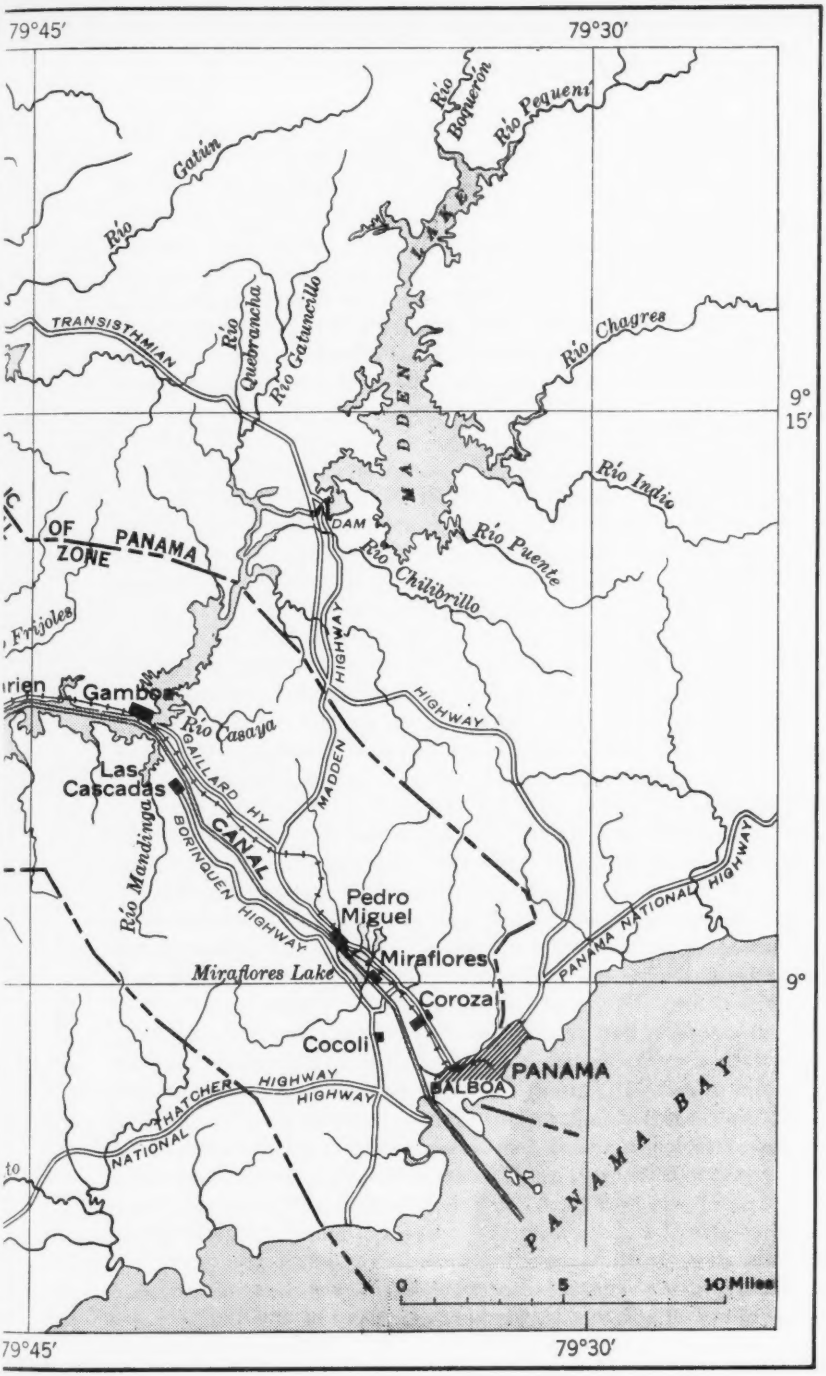


FIG. 1.—Map of Panama Canal Zone



and adjoining parts of Panama.

During the period from 1938 to 1948 an extensive program of subsurface and surface investigations was carried out, principally in connection with the Third Locks and the Sea-level Conversion Route projects. The reports on those projects include discussions of the geology (Thompson, 1943, 1943a, 1947, 1947a).

When *Bulletin 103* of the United States National Museum was published, the mollusks, which are the most abundant fossils in most of the fossiliferous formations, were omitted, as the collections had not been studied. They are now being studied by Woodring. This project included 2 months of field work in the Canal Zone early in 1947. At that time the results of recent geological work were available through the generous cooperation of Colonel James H. Stratton, supervising engineer in charge of the Special Engineering Division, and the geological staff of that division.

The purpose of the present paper is to bring up to date knowledge concerning the stratigraphy and age relations of the Tertiary formations. The stratigraphic data are based on investigations by Thompson and his assistants. Special acknowledgment should be made to S. K. Bartholomew, L. H. Henderson, S. M. Jones, J. M. Matthews, T. G. Moran, J. R. Schultz, R. H. Stewart, J. A. Tavelli, and L. C. Woolfe. The new formation and member names—Gatuncillo formation, Quebrancha limestone member of Caimito formation, La Boca formation, and Pedro Miguel agglomerate—have been proposed by Thompson in official Panama Canal reports, but now appear for the first time in a publication generally available to geologists. They are to be cited as Thompson's names. The discussion of the fossils and of age assignments, based on available paleontologic data, including the results of a preliminary examination of 200 collections of mollusks, was prepared by Woodring.

The principal localities mentioned are shown in Figure 1. Supplementary data are drawn from areas in near-by parts of Panama east and west of the Canal Zone. Madden basin is a structural and topographic basin along the upper Río Chagres and its tributaries, east of the Zone. The Quebrancha syncline, also east of the Zone, is northwest of Madden basin. It is crossed by the Transisthmian Highway along and near Río Gatuncillo. Suggested correlations between the different areas are shown in Figure 2.

The essential features of the stratigraphy are now fairly well established. Some former interpretations are known to be erroneous and further modifications are inevitable. Details of the stratigraphy at many places are obscure. Geological investigations in the Canal Zone, as in most tropical countries, are slow and difficult. Many of the lithologic units are lenticular; changes in lithologic and faunal facies are common; and faults have been found to be so numerous that determination of stratigraphic position on a basis of regional relations is hazardous. Correlations between different areas are for the most part difficult. Almost all the sedimentary formations are tuffaceous and some consist principally, or wholly, of tuff and other volcanic products. Southern Panama west of the Canal Zone appears to be the source of most of this volcanic material.

GATUNCILLO FORMATION

Quebrancha syncline.—The late Eocene Gatuncillo formation is the oldest known Tertiary formation in the Canal Zone and adjoining parts of Panama. The name for this formation, in the form Gatuncillo shale, was proposed in a Panama Canal report (Thompson, 1944, pp. 12–13). The most accessible exposures of the entire formation are in the type region, the Quebrancha syncline. In the type region the Gatuncillo formation consists chiefly of mudstone, siltstone, impure bentonite, and thin lenses of limestone. Unless it is duplicated by strike faults, which would be difficult to detect, its thickness is as much as 3,000 feet. It unconformably overlies a basement complex of unknown, possibly Cretaceous, age consisting of strongly deformed altered volcanics—flows, pyroclastics, and indurated fine-grained sediments that probably were originally fine-grained tuffs. The base of the Gatuncillo is well exposed in a cut on the Transisthmian Highway 0.7 mile east-southeast of Río Gatuncillo. Conglomerate, 1–3 feet thick, resting on the basement of altered volcanics, is overlain by 25 feet of medium- to fine-grained standstone, the upper part of which is silty. The bulk of the formation is made up of mudstone and siltstone, exposed along Río Gatuncillo and its tributaries. Foraminifera are common in these fine-grained rocks. R. H. Stewart identified about 110 species in 4 samples from the Quebrancha syncline and from the next outcrop area on the northwest. Thin lenses of limestone are found in the upper part of the formation. One of these lenses, near the east abutment of the Transcontinental Highway bridge across Río Quebrancha, contains numerous specimens of the large selliform species, *Lepidocyclina chaperi*, and a few of *Lepidocyclina* cf. *pustulosa*.

Madden basin.—The Gatuncillo formation also crops out in Madden basin. The geology of part of the basin was briefly described by Reeves and Ross (1930) and by Kellogg (1931). Presumably all of the Bohio formation of Reeves and Ross (p. 17) is to be included in the Gatuncillo formation. The thickness of 300–500 feet cited for Reeves and Ross' Bohio formation indicates that the formation is thinner than in the Quebrancha syncline, but the maximum thickness is probably at least 1,000 feet. Limestone in thin beds is found throughout the formation. At some localities, particularly near the borders of the basin—for example, at Salamanca gaging station on Río Pequení and at the natural bridge on Río Puente—units made up almost wholly of limestone are as much as 300 feet thick. The thick limestones grade basinward into mudstone containing thin beds of limestone. At some places the altered volcanics on which the formation rests are intruded by dioritic rocks. The name Tranquilla shale was proposed for late Eocene strata in Madden basin (Coryell and Embich, 1937, pp. 289–90). That name, however, was inadequately defined and the specified type locality, at and near the village of Tranquilla on Río Chagres, is flooded by Madden Lake.

Foraminifera (Vaughan, 1926; Coryell and Embich, 1937), echinoids (Cooke, 1948), and mollusks point to a late Eocene age. Orbitoids, including *Lepidocyclina chaperi*, are found in many of the limestones. *Lepidocyclina chaperi* was based

on specimens collected during French operations at San Juan, on Río Pequení, a tributary of the upper Chagres. Though Douvillé (1915, p. 130) recorded the association of *Lepidocyclina* and "*Asterodiscus*" in a sample from the upper Chagres, and though Cushman (Vaughan, 1919b, footnote to table opposite p. 595) thought that association indicates a late Eocene age, the age of the orbitoid-bearing limestones remained uncertain, because Douvillé assigned them to the Oligocene. Later Vaughan (1926) found that in a collection from the type locality, which is submerged by Madden Lake, *Lepidocyclina chaperi* is, indeed, associated with late Eocene species of larger foraminifera. The species from the Culebra and Caimito formations recorded as *L. chaperi* (Cushman, 1918a, pp. 92–93) is not that species (Vaughan, personal communication). The foraminifera described by Coryell and Embich are evidently from the lower part of the formation. The echinoids recently recorded by Cooke were collected from limestone, probably near the top of the formation, at Madden Airfield, near Río Puente. Mollusks from the limestone at Madden Airfield include *Velates* cf. *perversus*, *Spondylus* cf. *olssoni*, *Corbis* cf. *jamaicensis*, and "*Trigoniocardia*" cf. *samanica*. *Velates* cf. *perversus*, *Terebellum* cf. *procerum*, *Ectinochilus* cf. *gaudichaudi*, and *Pseudomiltha* cf. *megameris* have recently been collected at near-by localities. Though fossils so far collected from the Gatuncillo formation in both Madden basin and the Quebrancha syncline indicate a late Eocene age, systematic collections have not yet been made from the entire formation. It is unlikely, however, that the formation includes deposits older than late Eocene.

Canal Zone.—Three areas of the Gatuncillo formation, bounded in part by faults, have recently been found in the eastern part of the Canal Zone. One area lies northeast of Bohio Peninsula, along the alignment of the Chagres diversion channel for a proposed Panama sea-level canal. Another area of about 4 square miles is 3½ miles northwest of Gamboa, within the drainage basin of Río Frijoles and adjacent small streams. The third area is near the headwaters of Río Casaya, 2 miles southeast of Gamboa. In the first two areas the formation consists chiefly of mudstone, siltstone, and limestone; in the third area only limestone crops out. Limestone from a core hole located in the area northeast of Bohio Peninsula and from outcrop float at the core-hole site contains late Eocene larger foraminifera (Cole, awaiting publication). *Lepidocyclina chaperi* and *Spondylus* cf. *olssoni* have been found in the second area, *Velates* cf. *perversus* and *Cerithium* cf. *mariensis* (and cf. *vinctum*) in the third area.

The pre-Gatuncillo basement complex is also present in the eastern part of the Zone north of Gamboa in a region that has been explored along the alignment of the proposed diversion channel.

BAS OBISPO FORMATION, LAS CASCADAS AGGLOMERATE, AND BOHIO FORMATION

Canal Zone.—The Bas Obispo formation, Las Cascadas agglomerate, and Bohio formation, all of which are tentatively considered early Oligocene in age, are the oldest formations along the Canal. The pyroclastic Bas Obispo formation

and Las Cascadas agglomerate are interpreted to represent an accumulation of volcanic products at the periphery of a volcanic pile. Outward from the periphery the Bas Obispo formation grades into the detrital Bohio formation. The probable outward equivalent of the Las Cascadas agglomerate, provisionally designated the basal member of the Caimito formation, is discussed under the heading "Caimito formation." The Bas Obispo formation and Las Cascadas agglomerate crop out near Gamboa and in the northern part of Gaillard Cut.[4] The Bohio formation is found at localities near Gamboa and extends northwestward into the Gatun Lake area as far as Bohio Peninsula and Barro Colorado Island, and perhaps a little farther.

The Bas Obispo formation was described by Howe (1907, pp. 110–12; 1908, pp. 213–15), who used the designations Obispo formation and Obispo breccias. He included in the formation the pyroclastics later named the Las Cascadas agglomerate by MacDonald (1913, p. 568; 1913a, p. 708; 1919, p. 526). Northern Gaillard Cut is the type region for both formations. Agglomerate is the chief constituent of the Bas Obispo formation. The angular to subangular fragments of andesite and basalt are embedded in hard tuff. Pebbles and cobbles are local constituents, and at some localities crude bedding is apparent. The overlying Las Cascadas agglomerate was differentiated principally because it is less indurated and contains a higher percentage of altered fine-grained volcanic material than the Bas Obispo formation, and therefore has different engineering properties. The matrix of the agglomerates of the Las Cascadas consists of waxy and clayey altered tuff. Fine- to coarse-grained well bedded tuffs are interbedded with the agglomerates. Both formations include minor andesitic and basaltic flows and dikes. The thickness of both formations is undetermined and no fossils have been found in either. An early Oligocene age for them is questionable, despite the unequivocal designation in Figure 2.

The Bohio[5] formation was first named by Hill (1898, p. 183), who used the spelling Bujio. Current usage is based principally on MacDonald's redefinition, summarized in his 1919 publication (MacDonald, 1919, pp. 526–27). MacDonald's designation Bohio conglomerate calls attention to the most conspicuous constituent of the Bohio at many places, but Bohio formation is in general preferable. Many of the localities described by early writers, including the French quarries at Bohio and the excavation at the near-by lock site, are covered by Gatun Lake. Bohio, or Bohio Soldado, was a station on the original line of the Panama Railroad, near the southwest end of the ridge forming the present Bohio Peninsula. Bohio Peninsula may be regarded as the type region.

[4] Gaillard Cut, formerly known as Culebra Cut, extends from the south end of the Panama Railroad bridge at Gamboa southward to the north end of Pedro Miguel Locks. It includes the Canal excavation across the continental divide.

[5] For those who wish to preserve the original Spanish orthography Bohio should be written Bohío and Gatun should be Gatún. The accent marks are omitted in the present paper, inasmuch as these place names are in use in the Canal Zone in anglicized form. The name of the country is, of course, Panamá. It seems stilted, however, to refer, perhaps in the same sentence, to the Panama Canal Zone and Panamá.

The Bohio formation consists of massive or poorly bedded conglomerate, tuffaceous sandstone, and tuffaceous siltstone. The coarse constituents of the conglomerates are angular to rounded and range in size from small pebbles to boulders, exceptionally as much as 6 feet in diameter. They are embedded in dark gray coarse-grained sandstone, most of the grains of which are angular. Both coarse and fine constituents are chiefly basaltic. An increase in coarseness of matrix and in percentage of angular constituents is apparent between Darien and Gamboa, and southward from Gamboa conglomerates merge into agglomerates of the Bas Obispo formation (Jones, 1947, pp. 20–21). The thickness of the Bohio formation, estimated to be as much as 1,000 feet, is uncertain, as the structure of much of the outcrop area is complex. The base of the formation is not exposed along the Canal, but is exposed on Río Frijoles where basalt-pebble conglomerate unconformably overlies the Gatuncillo formation. Basaltic intrusions are common, particularly near Darien and Gamboa.

Much of the Bohio formation is probably non-marine, as suggested by Howe and MacDonald. Silicified tree trunks occur in the formation. *Lepidocyclina canellei* has been recognized by R. H. Stewart in calcareous pebbly sandstone, presumably part of the Bohio formation, at a locality near Darien. Fossiliferous marine strata formerly exposed at Vamos Vamos[6] are inferred to represent the Bohio formation. The fossil locality was located on the south bank of the French canal, corresponding with a position about $\frac{1}{4}$ mile northeast of Palenquilla Point—the north end of the first promontory west of Barro Colorado Island. The fossils were found in dark-colored tuffaceous silty sandstone, or siltstone, containing fossiliferous dark-colored calcareous concretions (Hill, 1898, pp. 179–180; Howe, 1908, p. 219; MacDonald, 1919, p. 542). Fossiliferous calcareous concretions occur in tuffaceous sandstone at Palenquilla Point. Though the fossils in a concretion from that locality are poorly preserved, they include *Turritella* cf. *galvesia* and *"Cardium" gatunense*, both of which occur at Vamos Vamos. The regional pattern suggests that the fossiliferous strata at Palenquilla Point overlie the Bohio formation of Barro Colorado Island and Bohio Peninsula, but the relations are uncertain because of faults. It is not unreasonable to expect marine tongues in the Bohio formation outward from the source of the volcanic material forming the coarse conglomerates. The Vamos Vamos and Palenquilla Point localities are northwest of the outcrop area of the conglomerates and are inferred to represent marine strata in the Bohio formation.

About 50 species of mollusks are in collections from Vamos Vamos, including the type material of *Glyptostyla panamensis*, *Mactrella dariensis*, *Pitar* (*Costacallista*) *hilli*, and *"Cardium" gatunense*, the specific name of the last species being misleading. *Glyptostyla panamensis* is the type of the genus *Glyptostyla*. The Peru-

[6] This locality has also been called Vamos-à-Vamos. That designation is clearly French; in fact, Vamos Vamos itself, which appears on French maps, is doubtless a French modification of an unusual locality name that probably dates from the time when Americans traveled up Río Chagres on their way to California.

vian late Eocene and Oligocene genus *Peruficus*, found also in the late Eocene of Colombia, is doubtless *Glyptostyla*. As already pointed out by MacNeil (1940, p. 508), the fossils from Vamos Vamos include the early noetid genus *Samanoetia*, which occurs in the late Eocene and Oligocene of Peru and in the late Eocene of Colombia. A *Turritella*, Dall's *T. gatunensis*, is similar to the Peruvian Oligocene *T. galvesia*. *Mactrella dariensis* is a small species, evidently the earliest representative of an essentially late Tertiary and Recent genus found also in the Peruvian Oligocene. "*Cardium*" *gatunense* and the Peruvian late Eocene "*Trigoniocardia*" *samanicum* apparently represent an early Tertiary predecessor of *Trigoniocardia*. Dall thought the fossils from Vamos Vamos are Eocene (Hill, 1898, pp. 271, 273; Howe, 1908, pp. 219–20). They have some late Eocene affinities, but on grounds other than those postulated by Dall. They have also Oligocene affinities, and the absence of typical Eocene genera indicates an early Oligocene age. An early Oligocene age assignment for the Bohio formation of the Canal Zone, however, must be considered provisional, as the age evidence is based on an inference that may be unverifiable. Nevertheless the relations of the Bohio to dated formations in the Canal Zone and fossils from the Bohio in the Quebrancha syncline show that the age assignment is reasonable.

The age relations of the fossils from Vamos Vamos were not recognized at an early date, because Hill included in his Vamos Vamos material a collection of fossils that certainly is from a locality near Gatun, though he listed it as a Vamos Vamos collection. The original list of field numbers and locality data, in Hill's writing, is preserved among Dall's papers. On account of Hill's clearly erroneous locality data, Dall thought that other collections from Gatun, which include species in Hill's alleged Vamos Vamos collection, are Eocene. It should have been evident to Dall, however, that one of Hill's collections labelled Vamos Vamos is different from the others, not only in faunal association and the absence of any species of genuine Eocene affinities, but also in rock matrix. That simple observation, which is obvious when Hill's collections are sorted out according to their field numbers, was missed at a much later date when an early middle Miocene age was suggested for Hill's mixture of fossils from Gatun and Vamos Vamos (Woodring, 1928, p. 76)—an estimate worse than Dall's. As a matter of fact, when A. A. Olsson briefly examined Hill's Vamos Vamos collections in 1932, he thought they included a mixture of species from Gatun, but the matter was not pursued at that time.

Madden basin.—The probable equivalents of the Bohio formation and Las Cascadas agglomerate in Madden basin and the Quebrancha syncline are designated the Bohio formation. Along the Transisthmian Highway, on the southeast border of Madden basin and farther southeast on both sides of the continental divide, the Bohio formation is represented by coarse conglomerate and poorly sorted gritty sandstone of undetermined thickness. At and southeast of the continental divide it includes thin lenses of pebbly or sandy algal limestone contain-

ing a few specimens of *Lepidocyclina* that have not yet been identified. According to field identifications, they suggest Antiguan species.[7] In the basin proper, conglomerate and gritty sandstone in the lower part of the Culebra formation of Reeves and Ross (1930, p. 16) evidently represent the Bohio formation, suggesting a northward decrease in coarseness and thickness.

Quebrancha syncline.—In the Quebrancha syncline (Thompson, 1944, pp. 13–17), the strata now assigned to the Bohio formation consist of a gritty sandstone member and an overlying volcanic member. The gritty sandstone member, made up of poorly sorted gritty sandstone and lenses of conglomerate, conformably overlies the Gatuncillo formation. It has a thickness of 1,500 feet and is considered the equivalent of the Bohio formation of the Canal Zone. Though much of this member is doubtless non-marine, the basal part contains well preserved foraminifera. The fauna of about 35 species is correlated by R. H. Stewart with that of the early Oligocene Alazan formation of Mexico. The volcanic member, consisting in ascending order of a basalt flow, agglomerate, and greenish waxy slickensided clay of altered tuffaceous composition, is 100 feet thick. It presumably is to be correlated with the Las Cascadas agglomerate.

CAIMITO FORMATION

Canal Zone.—In the Canal Zone the Caimito formation is found only in the Gatun Lake area on the Caribbean side of the Zone. Though the formation name was introduced many years ago by MacDonald (1913, p. 569; 1913a, p. 709), it was not properly defined then or later (MacDonald, 1919, p. 531). It may be assumed that the type region, which was not specified, is the region that furnished the name. Caimito, or Caimito Junction, was located on the present alignment of the Panama Railroad near Darien (MacDonald, 1919, Fig. 27, p. 529). Most of MacDonald's brief description of the formation is a description of strata on the Pacific side of the Canal Zone now assigned to the La Boca formation. His statement that the Caimito formation overlies the Emperador limestone—now assigned member rank in the Culebra formation—was based on misidentification of limestone in the La Boca formation and in the Caimito itself. The Caimito formation and Emperador limestone member of the Culebra formation are nowhere in contact. Limestone at various horizons in the lower member of the Caimito was designated the Emperador limestone and other fossiliferous Caimito strata were assigned to the Culebra formation. On account of these confusing formation assignments, published data on the fossils of the Caimito and Culebra formations, including the Emperador limestone member, are misleading or erroneous.

The Caimito formation is divided into lower and upper members, the lower member being represented in the type region—the Darien region. Strata that may represent the equivalent of the Las Cascadas agglomerate are provisionally

[7] Since this account was written, W. Storrs Cole has confirmed the occurrence of Antiguan species, including *Lepidocyclina parvula*, *L. waylandvaughani*, *L. favosa*, and *L. gigas*.

designated the basal member (Jones, 1947, pp. 24–25). The basal member rests on the Bohio formation and in the absence of the basal member the lower member overlies the Bohio. Where the basal member is missing, there evidently is a discontinuity between the Bohio and Caimito formations. The thickness of the Caimito formation, which may be as much as 1,000 feet or more, is difficult to estimate. Much of the area underlain by the formation is submerged by Gatun Lake and was covered by swamps before the flooding of the lake. Faults are numerous and reliable stratigraphic guides for building up a composite section are not evident.

The Caimito formation is characterized by the prevalence of tuff of acidic composition, probably for the most part rhyolitic, as indicated by petrologic studies made for Hill (1898, pp. 185–86). The basal member consists of conglomerate. It crops out near Darien and on Barro Colorado Island. The cobbles and boulders are basaltic, but some of the pebbles are composed of tuff. The sandstone matrix, unlike the matrix of conglomerates of the Bohio formation, contains acidic tuff. Tuffaceous sandstone and thin beds of limestone are the chief constituents of the lower member. The upper member, the thickest and most widespread part of the formation, is made up of tuff, agglomeratic tuff, tuffaceous siltstone, and sandy tuffaceous limestone. In both lower and upper members the limestone beds are thin and discontinuous.

No fossils have been found in the basal member, and it is not known whether it is marine. If it is the equivalent of the Las Cascadas agglomerate, it is presumably of questionable early Oligocene age. Limestone in the lower member contains numerous specimens of *Lepidocyclina canellei*, *Lepidocyclina vaughani*, and other larger foraminifera. The type material of *Lepidocyclina canellei* was collected during French operations at Peña Blanca on the south bank of Río Chagres. This submerged locality is off the entrance to the little bay separating the westernmost main promontory on the north side of Barro Colorado Island from the next main promontory on the east. The regional relations indicate that the marly limestone at Peña Blanca was in the Caimito formation close to the base of the lower member. The type locality of *Lepidocyclina vaughani* is the first cut on the Panama Railroad northwest of Darien. This locality is in the type region of the Caimito formation, and the fossiliferous sandy limestone, identified by MacDonald as the Emperador limestone (MacDonald, 1919, p. 539, locality 6021), is not far above the base of the lower member.

Vaughan and MacDonald collected corals from the lower member of the Caimito formation at two localities on the Panama Railroad. One locality was assigned to the Culebra formation (Vaughan, 1919a, p. 208, locality 6026; MacDonald, 1919, p. 541), the other to the Emperador limestone (Vaughan, 1919a, p. 209, locality 6024b; MacDonald, 1919, p. 540). According to Vaughan's lists, 4 of the 7 species occur in the Antigua formation of the island of Antigua, and one in the Anguilla formation of the island of Anguilla. The preponderance of Antiguan species favors a late Oligocene age for the Caimito corals.

About 30 species are represented in collections of mollusks from the lower member of the Caimito formation at localities on the Panama Railroad. One of these localities (locality 6025, second cut southeast of Bohio Peninsula) is the type locality of *Lepidocyclina pancanalis* and *Miolepidocyclina panamensis*. The mollusks include the Peruvian late Oligocene species *Turritella meroensis*, a weakly sculptured form of *Turritella altilira*, *Orthaulax* cf. *pugnax*, *Globularia*, a form of *Pecten* (*Flabellipecten*) *gatunensis*, and *Lyropecten* (*Nodipecten*) cf. *condylomatus*. *Turritella meroensis* suggests late Oligocene, and the other Caimito mollusks are not opposed to that age assignment. *Nodipecten* is unknown in the Oligocene of southeastern United States and the West Indies, unless the Cuban *L.* (*N.*) *articulosus* is of Oligocene age. A species related to the Florida early Miocene *L.* (*N.*) *condylomatus*, however, is recorded from limestone in Trinidad assigned to the upper Oligocene (Renz, 1942, p. 549; Stainforth, 1948, p. 1311).

Fossils are rare in the upper member of the Caimito formation. Calcareous sandstone on Puma Island contains a small *Lepidocyclina*, probably *L. canellei*.

The paleontologic data uniformly point to a late Oligocene age for the lower member of the Caimito formation. The upper member is probably late Oligocene, and the provisional basal member may be early Oligocene.

Quebrancha syncline.—Two members of the Caimito formation are represented in the Quebrancha syncline: the Quebrancha limestone member and the calcareous siltstone member. On account of its economic importance, the Quebrancha limestone member was named as a separate formation in a Panama Canal report (Thompson, 1944, pp. 17–20). The type region, on the south limb of the syncline, includes the quarry of the Panama Cement Company, near Río Quebrancha. The Quebrancha limestone member has a thickness of 350–450 feet. It overlies, probably without marked discontinuity, the volcanic member of the Bohio formation. As shown by core holes, the thin basal part consists of calcareous siltstone grading upward into calcareous medium-grained sandstone. The bulk of the member consists of limestone, much of which is made up principally of a *Lepidocyclina*, identified by H. G. Schenck as *L. vaughani*. Soft marly layers in the lower part of the limestone contain *Turritella meroensis* and a weakly sculptured form of *T. altilira*. Both occur in the lower member of the Caimito formation in the Canal Zone, supporting correlation with that member and a late Oligocene age.

The Quebrancha limestone member grades upward into the calcareous siltstone member, which includes tuffaceous pumice-bearing siltstone and medium-grained calcareous sandstone, as well as calcareous siltstone (Thompson, 1944, pp. 20–21). The calcareous siltstone member has an exposed thickness of about 1,000 feet, but its full thickness is unknown as it is bounded by a fault. It is probably the equivalent of at least part of the upper member in the Canal Zone and is the youngest Tertiary lithologic unit in the Quebrancha syncline. *Lepidocyclina canellei* has been recognized by R. H. Stewart in this member.

Madden basin.—Five lithologic units exposed along the Transisthmian High-

way in the southern part of Madden basin are assigned member rank under the Caimito formation. Two of the members have been formally named. It has already been suggested by Olsson that the upper three members are to be grouped in the Caimito formation (Olsson, 1942, pp. 234, 243). The maximum thickness of the formation in this region is about 1,100 feet. Though the data still are incomplete, the members are briefly described in ascending order in the following paragraphs.

The lowest member, designated the calcareous sandstone-siltstone member, overlies the Bohio formation. Its thickness is about 300 feet. On the west border of the basin, where it is faulted against the basement complex, this member contains numerous specimens of *Lepidocyclina vaughani*. Kellogg's (1931, pp.115–18) grits formation evidently is the equivalent of the calcareous sandstone-siltstone member. The pyroclastic-clay member, which has a maximum thickness of about 350 feet, includes agglomerate, conglomerate, tuff, clay, and a limestone lens that has a maximum thickness of 140 feet. *Lyropecten* (*Nodipecten*) cf. *condylomatus*, collected from the limestone, evidently is the species that occurs in the lower member of the Caimito formation in the Canal Zone. The pyroclastic-clay member and the underlying calcareous sandstone-siltstone member are thought to be late Oligocene. Both were included by Reeves and Ross (1930, pp. 16–17) in their Culebra formation. Kellogg's (1931, pp. 111–114) clay formation, which is lenticular, is the equivalent of part of the pyroclastic-clay member. The agglomerate in the pyroclastic-clay member appears to be a local facies at the southeast border of the basin. It is not represented in the central part of the basin. No pyroclastics are recognized in the Caimito formation of the Quebrancha syncline, with the exception of tuffaceous material in the calcareous siltstone member.

The Chilibrillo limestone member is the Emperador limestone of Reeves and Ross (1930, pp. 15–16) and the limestone formation of Kellogg (1931, pp. 110–11). It may, in fact, be the essential equivalent of the Emperador limestone member of the Culebra formation. The name Chilibrillo was used casually by Olsson (1942, p. 234). The type region is on the east side of the basin between Madden Lake and Río Chilibrillo (see Reeves and Ross, geologic map, Pl. 5). The maximum thickness of the limestone is 100 feet. It pinches out southward on both sides of the basin. Collections of fossils from this member are not extensive. *Lyropecten* (*Nodipecten*) cf. *nodosus* and *Ostrea* cf. *gatunensis* favor a Miocene age, presumably early Miocene.

The calcareous sandstone member, 100 feet thick and consisting of calcareous tuffaceous sandstone, was designated by Reeves and Ross (1930, p. 15) as the Caimito(?) formation and by Kellogg (1931, p. 110) as member 2 of his sandstone formation. It is without much doubt early Miocene. The few mollusks collected from it include *Turritella* cf. *gatunensis*.

The Alhajuela sandstone member, the Gatun(?) formation of Reeves and Ross (1930, pp. 14–15) and member 1 of the sandstone formation of Kellogg (1931, pp. 108–09), is the youngest Tertiary lithologic unit in Madden basin.

The name Alhajuela sandstone was proposed by Olsson (1942, pp. 234, 243), who used the spelling Alajuela. This member is found only in the type region, a small area at and near Madden Dam in the central part of the basin, including the site of the former village of Alhajuela (see Reeves and Ross, geologic map, Pl. 5). The massive fine- to coarse-grained tuffaceous sandstone of the Alhajuela member has a thickness of 275 feet. It forms the abutments of Madden Dam. Mollusks are common or abundant, particularly the typical form of *Pecten* (*Flabellipecten*) *gatunensis* and an *Aequipecten* of the *A. gibbus* group. The fossils include also the typical form of *Turritella altilira*, *Anomia* cf. *berryi*, *Lyropecten* (*Nodipecten*) cf. *nodosus*, *Macrocallista* cf. *maculata*, *Dinocardium*, and *Corbula* cf. *hexacyma*. The Alhajuela sandstone member is late early Miocene or possibly early middle Miocene. The faunal association is different from any in the middle and late(?) Miocene Gatun formation and shows affinities with the early Miocene Zorritos formation of Peru and the early Miocene strata of Colombia. Nevertheless, so far as now known, it can not be satisfactorily demonstrated that the Alhajuela faunal association is older than Gatun associations.

The Caimito formation of Madden basin includes a considerable time span—late Oligocene to late early Miocene, or possibly early middle Miocene.

CULEBRA FORMATION, INCLUDING EMPERADOR LIMESTONE MEMBER

Canal Zone.—The Culebra formation has a restricted distribution along and near the Canal in the Gaillard Cut area and immediately southeast of the cut. Central Gaillard Cut, where the town of Culebra was located during the construction period, is the type region. The name for the formation, in the form Culebra clays, was first used by Hill (1898, pp. 192–95). The Culebra formation unconformably overlies the Las Cascadas agglomerate. The maximum thickness is estimated to be a little more than 500 feet. The thickness decreases northward, evidently owing to overlap of successively younger parts of the formation on the Las Cascadas agglomerate.

MacDonald (1913, pp. 568–69; 1919, p. 527) divided the Culebra formation of the type region into lower and upper parts. The lower part is characterized by dark-colored fine-grained rocks—carbonaceous shale, thin layers of lignite, carbonaceous silty mudstone, tuffaceous siltstone—but includes minor beds of tuffaceous and calcareous sandstone and conglomerate. Many of the fine-grained rocks are thinly bedded, and some contain the remains of land plants. Calcareous beds, ranging in thickness from 1 to 10 feet and in composition from calcareous tuffaceous pebbly sandstone to sandy limestone, are the most conspicuous constituents of the upper part. These calcareous beds are separated by thicker units of dark-colored calcareous or somewhat carbonaceous shale and mudstone.

At most localities the Culebra formation is overlain abruptly by conglomerate at the base of the Cucaracha formation. On both sides of Gaillard Cut, just northwest of the site of Culebra, a transition zone between the formations includes fossiliferous, somewhat calcareous, silty sandstone, and clay like that of the

Cucaracha formation. This transition zone is grouped with the Culebra formation.

Massive cream-colored coralliferous limestone, formerly exposed in shallow quarries at Empire, was named the Empire limestone by Hill (1898, pp. 195–96). Empire, now abandoned, was a village on the original line of the Panama Railroad near Culebra and about half a mile west of Gaillard Cut. The name was later altered to Emperador limestone (MacDonald, 1913, p. 569; 1913a, p. 709). The alteration was presumably made on the grounds of possible confusion with the Tertiary Empire formation of Oregon. Though the possibility of confusion is remote, the name Emperador limestone is appropriate, as Empire is an American emendation of the Spanish name for the village. The quarries at Empire, the type region, are now unrecognizable. According to the regional relations, however, the limestone—or limestones, for more than one limestone may have been represented at the quarry sites—is in the Culebra formation. Inasmuch as coralliferous pure limestone is a local minor constituent of the Culebra formation, the Emperador limestone is of member or lower rank.

Limestone is so rare along the Canal and is so conspicuous in the mass of predominantly tuffaceous rocks that such beds in different regions were formerly correlated with the Emperador limestone. As a result of these correlations, limestones in the Caimito and La Boca formations, and even in the Gatuncillo formation of Madden basin, were designated the Emperador limestone. Even when limestones in other formations are eliminated there remains a residue of limestones in the Culebra formation, the relative stratigraphic position of which is uncertain. Subsurface and surface data indicate that these coralliferous pure limestones are the local equivalent of calcareous sandstone and sandy limestone at different horizons in the Culebra formation, evidently in MacDonald's upper part. The coralliferous limestone represents deposition in clear water, protected from the detrital material that formed the bulk of the Culebra formation. Pure limestone is found only in the northern part of the outcrop area of the Culebra formation, suggesting that it extended seaward from the shore of the Culebra sea lapping against the Las Cascadas agglomerate. That limestone of Emperador type rests directly on the Las Cascadas agglomerate is shown by exposures on Río Masambí, a stream entering the east side of Gaillard Cut at Canal station 1696.[8] The limestone on Río Masambí has a thickness of 120 feet, the greatest known thickness for limestone of Emperador type. Unfortunately there are no exposures to show what overlies it. It may be assumed, however, that it is in the Culebra formation. Similar but thinner limestone lies in the Culebra formation farther northwest on the west side of Gaillard Cut near Canal stations 1619 and 1600. Near station 1619, where the limestone is 40 feet thick, it is about 90 feet above the base of the Culebra formation. Near station 1600 the limestone is 20 feet thick and was found to be 80 feet above the base of the Culebra formation in a near-by

[8] The Canal stations are located at intervals of 100 feet and are numbered from the Caribbean terminus to the Pacific terminus.

core hole. The limestone near station 1619 is doubtless the extension of limestone described in fossil-locality data as the limestone at Tower N, a signal tower on the original line of the Panama Railroad on the west side of Gaillard Cut. Though more than one horizon may be represented, the limestone at the localities mentioned is assigned to the Emperador limestone member. This action should not have any serious effects in paleontologic data, as it is unlikely that a limestone in the Culebra formation could be differentiated by its fossils from older or younger similar limestone in the formation.

Lepidocyclina canellei is doubtfully recorded from the Culebra formation (Cushman, 1918a, p. 92, locality 6019a), and an indeterminable Culebra species of *Lepidocyclina* is recorded as *L. chaperi* (Cushman, 1918a, p. 93, locality 6019f). *Lepidocyclina canellei* was identified by H. G. Schenck in core samples from horizons 100 to 150 feet below the top of the formation. A collection of mollusks from the Emperador limestone member of the Culebra at Tower N includes an unidentified *Lepidocyclina*. Smaller foraminifera, considered of Oligocene age by Schenck, are found in fine-grained rocks of the formation. Core material, examined by Schenck, shows that the published records are inadequate (Cushman, 1918, pp. 49–50; localities 6009 and 6010 represent the La Boca formation; localities 6024a, 6025, and 6026 the Caimito formation).

Four species of corals from the Culebra formation at localities 5853 and 6020c in Gaillard Cut were recorded by Vaughan. Three occur in the Antigua formation and 4 in the Anguilla formation (Vaughan, 1919a, p. 208; locality 5853 cited as 5863). Vaughan recorded 24 species of corals from the Emperador limestone member of the Culebra in the type region (Vaughan, 1919a, p. 209). According to his lists, 4 occur in the Antigua formation and 9 in the Anguilla formation. Only one of the 4 species that occur in the Antigua formation has not been found also in the Anguilla formation. Vaughan listed 6 Antiguan species, but two were collected only at a locality in the Caimito formation (locality 6024b). The Emperador corals support correlation with the Anguilla formation.

Mollusks are common in the calcareous sandstones and sandy limestones, and a few occur in some of the fine-grained strata. Most of the collections were made during the excavation of Gaillard Cut, 39 collections containing about 140 species being available. The few early collections from the type region that can be unequivocally assigned to a stratigraphic position with reference to the division between lower and upper parts show no marked faunal differentiation. The data for many of the early collections from central Gaillard Cut, however, are inadequate for detailed stratigraphic assignment. The Culebra mollusks have both Oligocene and Miocene affinities. *Globularia* and *Nemocardium* point to early Tertiary; *Dosinia*, *Chione*, *Lirophora*, and *Trigoniocardia* are essentially late Tertiary and Recent genera. *Globularia* survived until early Miocene time in Anguilla and Florida. The Anguillan species is of disputed Oligocene or Miocene age, but the species from Florida is found in the Chipola formation, which is considered early Miocene by paleontologists familiar with its fauna. Though *Nemocardium* is not known in the Miocene of America, it is evidently still living in the China

Sea. On the other hand, *Dosinia* occurs in the late Oligocene of Peru; *Chione* in the late Oligocene of Peru, Ecuador, Antigua, and southeastern United States; and *Lirophora* in the middle and late Oligocene of southeastern United States. Species from the late Eocene of Peru and Colombia and from the late Oligocene of southeastern United States have been assigned to *Trigoniocardia*, but typical *Trigoniocardia* is still unknown in formations earlier than Miocene. Some Culebra species other than *Nemocardium* cf. *diversum* will doubtless be found to have Oligocene affinities when they are adequately studied. Nevertheless *Turritella* cf. *caparonis*, *T.* cf. *subgrundifera*, *Orthaulax* cf. *aguadillensis*, *Anadara* cf. *chiriquiensis*, *Macrocallista* cf. *maculata*, and *Trachycardium* cf. *dominicense* strongly suggest Miocene.

Oligocene affinities are not evident in the fauna from the local transition zone between the Culebra and Cucaracha formations. The fauna, however, represents an environment different from that of the calcareous sandstones and sandy limestones. It includes species indicating brackish water, and silicified wood riddled by ship worms is common. Fossils from localities in the upper part of the formation, not far below the top, in southern Gaillard Cut also do not show Oligocene affinities. On the contrary, they include the following species of Gatun affinities not known in the Culebra formation farther northwest: *Phos* cf. *gatunensis*, *Phos* cf. *metuloides*, *Murex* cf. *polynematicus*, and "*Strombina*" cf. *mira*, associated with *Northia*, *Paraterebra*, and *Glycymeris* cf. *acuticostata*, also unknown elsewhere in the Culebra. The uppermost part of the formation in southern Gaillard Cut is perhaps the equivalent of the transition zone, but represents an environment farther seaward.

About 35 species of mollusks, apparently all except 3 of which occur also in the Culebra formation proper, are in collections from the Emperador limestone member. They include species of *Dosinia*, *Chione*, *Lirophora*, and *Nemocardium*.

A late Oligocene(?) and early Miocene age is suggested for the Culebra formation, including the Emperador limestone member. The Culebra formation is thought to include the equivalent of the Anguilla formation of Anguilla and the Tampa limestone of Florida, but probably includes a greater time range than those formations. Much, if not all, of the Culebra is unequivocally late Oligocene to paleontologists who prefer a late Oligocene age for the European Aquitanian and its supposed American equivalents. *Lepidocyclina canellei* is a lepidocycline ("isolepidine") species. Some paleontologists consider the presence of lepidocycline species of *Lepidocyclina* to be decisive for an age not younger than Oligocene. In the Canal Zone and California, such species are found in formations that may be claimed to be Miocene.

The Culebra formation is not recognized in the Gatun Lake area on the Caribbean side of the Canal Zone or in Madden basin. The orbitoids suggest that the Culebra is the equivalent of part of the Caimito formation. It may, indeed, be the equivalent of the sparsely fossiliferous upper member of the Caimito in the Gatun Lake area. Despite the difference in coral and mollusk faunas, it may even be the equivalent of the lower member. Until a Culebra fauna is found

in the Caimito formation of Madden basin, which without any reasonable doubt includes the time equivalent of the Culebra formation, the restricted distribution of Culebra rocks and of most of the Culebra fossils point to some kind of environmental control. An exceptional environment—exceptional for Canal Zone Tertiary formations—of coastal-swamp mud or of black mud deposition in poorly aerated marine waters is evident for the carbonaceous fine-grained sediments of the Culebra formation, but no exceptional environment is apparent for the calcareous strata. Whatever the environments were, the restricted distribution of the soft rocks forming the bulk of the Culebra formation and of the soft rocks of the overlying Cucaracha formation determined the location of the Canal. These soft rocks form topographic basins separated by hills composed of agglomerate or basalt, or capped by those hard rocks, and the location of the basins on both sides of the continental divide determined the course of the Canal.

CUCARACHA FORMATION

Canal Zone.—The Cucaracha formation, which overlies the Culebra formation has a distribution somewhat similar to that of the Culebra, but extends farther away from the Canal. It was differentiated from the Culebra formation by MacDonald (1913, p. 569; 1913a, p. 709). The spelling Cucuracha used in some of MacDonald's publications is erroneous. The type region is along Gaillard Cut south of the continental divide, where the village of Cucaracha was located near the site of the Cucaracha slide. The maximum thickness of the formation is about 625 feet.

The Cucaracha formation is the most distinctive formation in the Canal Zone. It was responsible for many of the extensive slides during the construction period, and during recent years its engineering properties have been more exhaustively studied than those of any other formation in the Canal Zone. The bulk of the formation consists of massive, generally greenish gray, waxy, highly slickensided, bentonitic clay. Carbonaceous and lignitic shale, clayey siltstone containing characteristic light-colored small calcareous concretions, tuffaceous sandstone, and small-pebble conglomerate are for the most part minor constituents. A bed of agglomeratic andesitic tuff, known colloquially as the ash flow, is a reliable stratigraphic guide. It has a thickness of 10–35 feet and is about 200 feet below the top of the formation.

The base of the Cucaracha formation is generally abrupt and marked by conglomerate, indicating discontinuity, evidently a minor discontinuity. As mentioned under the heading "Culebra formation," there is a local transition zone between the formations.

Most of the Cucaracha formation is doubtless non-marine. It contains a few remains of land plants. Oysters and a small *Anadara* have been found in cores from thin conglomerate layers in the lower part of the formation. MacDonald collected poorly preserved specimens of *Anadara*, *Lucina?*, and *Tellina?* from carbonaceous shale in the lower part of the formation in Gaillard Cut (MacDonald, 1919, p. 536, locality 6012e). The early Miocene age for the formation shown in

Figure 2 is based on the same age assignment for underlying and overlying strata.

LA BOCA FORMATION, PEDRO MIGUEL AGGLOMERATE, AND PANAMA TUFF

Canal Zone.—The name La Boca formation was proposed in a Panama Canal report for marine strata at subsurface and outcrop localities, along and near the Canal, extending from Gaillard Cut southeastward to the Pacific Ocean (Thompson, 1943, pp. 16–17). The town of La Boca, which furnished the name, is located near the entrance to Balboa Harbor. Strata assigned to the La Boca formation were formerly referred to the Culebra formation, the Emperador limestone member of the Culebra formation, and the Caimito formation. There is no satisfactory outcrop section showing a considerable part of the La Boca formation and its stratigraphic relations. The Miraflores Locks area, where relations to the Cucaracha formation are shown by subsurface sections, is designated the type region. The maximum known thickness is 600 feet. Though the La Boca formation overlies the Cucaracha formation, the lower part of the La Boca is probably the southward marine equivalent of the upper part of the Cucaracha in the area of maximum thickness of that formation.

In subsurface sections and in excavations along the Canal, the La Boca formation consists chiefly of silty or sandy tuffaceous mudstone. Cross-bedded sandstone and conglomerate were encountered in some core holes penetrating the lower part of the formation. Flaggy calcareous sandstone, limestone, and fine-grained tuffaceous sediments are the principal constituents at the scattered outcrop localities. Cream-colored coralliferous limestone of Emperador type at the base of the formation may be seen to partly interfinger with clay of the Cucaracha formation at a locality on Gaillard Highway $\frac{1}{4}$ mile northwest of the Madden Highway turnoff.

The type locality of *Lepidocyclina miraflorensis*, a lepidocycline species, is evidently in the La Boca formation (locality 6255, "$\frac{1}{2}$ mile south of Miraflores station on wagon road to Panama;" probably the south slope of the hill, on which the water-treatment plant is located, $\frac{1}{3}$ mile north of the north entrance to Miraflores Locks). *Lepidocyclina* is also represented in MacDonald's collection of mollusks from the La Boca formation at a locality he designated Bald Hill, which is identified as the hill immediately north of Red Tank, between Pedro Miguel and Miraflores (MacDonald, 1919, p. 534). Vaughan recorded two species of corals from limestone at the same locality (Vaughan, 1919a, p. 209, locality 6256). Both species occur in the Emperador limestone member of the Culebra formation. Smaller foraminifera are abundant in core samples. They were examined by H. G. Schenck, who considers them to be late Oligocene in age. He identified *Siphogenerina transversa* in many collections from the La Boca formation, but that species was not found in the Culebra formation. Its type locality is in the La Boca formation, not the Culebra formation (Cushman, 1918, p. 64, locality 6010). About 20 species of mollusks are in collections from the La Boca formation. *Acila* cf. *isthmica* and *Aequipecten* cf. *gibbus* indicate Miocene, and an

early Miocene age is suggested for the formation. A collection from Gaillard Cut at a locality close to a fault between the Culebra and La Boca formations includes *Nemocardium*. The locality data are insufficient to determine which formation is represented by the collection.

The Pedro Miguel agglomerate is a lens of pyroclastics, formerly referred to the Las Cascadas agglomerate. In the Pedro Miguel area, the type region, the pyroclastics overlie the Cucaracha formation, but the lower part, like the lower part of the La Boca formation, is apparently the equivalent of the upper part of thick Cucaracha sections. Farther south in both subsurface and outcrop sections the pyroclastics occur as a tongue in the basal part of the La Boca formation. The thickness of the pyroclastics varies, but the maximum averages about 300 feet. The name for this formation was proposed in a Panama Canal report (Thompson, 1943, pp. 17–18). Fine- to very coarse-textured agglomerate is the principal constituent. The sandy to tuffaceous matrix is commonly cemented by secondary calcite. Bedding and sorting are poor to moderately well developed. Hard, dark-colored, fine-grained tuff is interbedded with the agglomerate.

The Panama tuff is evidently a tuff facies of the La Boca formation. The name for the formation, in the form Panama formation, was first used by Hill (1898, pp. 200–02). He described exposures along the water front in the city of Panama, which is considered the type region. The stratigraphic relations are not evident in that area, but toward the Canal the regional relations indicate that the tuff is the equivalent of the lower part of the La Boca formation. Its thickness has not been determined. Cuts in the Diablo Heights-Albrook Airfield area, between Balboa and Corozal, expose light-colored fine- to coarse-grained tuff. Rounded fragments of pumice are common in the coarse-grained tuff.

GATUN FORMATION

Canal Zone and adjoining parts of Panama east and west of Zone.—The Gatun formation was named by Howe (1907, pp. 113–14), but, because of what proved to be faulty paleontologic advice, he included the lowest beds at Gatun in the Bohio formation. Later evidently yielding reluctantly to the same paleontologic advice, he included still other strata at Gatun in the Bohio formation and used Hill's designation Monkey Hill formation for the remainder of the Gatun formation (Howe, 1908, pp. 219, 228–29). The type region of the Gatun formation extends from the bluff overlooking Gatun Lake near Gatun northward to Mount Hope, formerly known as Monkey Hill, near Colón. Neither the base nor the top of the formation is exposed in the type region. The thickness is greater than formerly supposed. A water well near Mount Hope penetrated a thickness of 1,400 feet without reaching the base of the formation.

In the Gatun Lake area west and southwest of Barro Colorado Island, the Gatun formation evidently rests on the Caimito formation, but details of the relations between them are unknown. Overlap of the Gatun formation is indicated by relations a few miles east of the Canal Zone, where conglomerate that appears to represent a non-marine basal part of the Gatun rests on the basement

complex (Jones, 1947, pp. 42–43). The outcrop area of the Gatun formation extends westward into Panama a short distance beyond Río Miguel, about 30 miles southwest of Colón, where it also overlaps the basement, and eastward to María Chiquita, 10 miles in an air line northeast of Colón.

In the Canal Zone the Gatun formation consists of massive sandstone, siltstone, conglomerate, and tuff. Most of the sandstone is fine-grained. The sandstone and siltstone are more or less calcareous or marly, and somewhat tuffaceous. The tuff is almost invariably very fine-grained and forms conspicuous light-colored outcrops in excavations. Basaltic intrusions penetrate older formations in the Gatun Lake area but are not known to occur in the Gatun formation.

Fossils, mostly mollusks, are abundant and at many localities are well preserved. They have attracted attention ever since California gold-rush travelers crossed Panama. About 80 collections of mollusks at the United States National Museum represent a collecting span of almost 100 years. They are estimated to contain about 350 species, a little less than half of which have so far been recorded as Gatun fossils. An earlier estimate of 400 species is probably too generous (Woodring, 1928, p. 76). East of the Canal a three-fold faunal division may be recognized, corresponding to the three-fold division of the formation proposed by Keen and Thompson (1946), which differs from three-fold divisions previously proposed (Woodring, 1928, pp. 76–78; Olsson, 1942, pp. 244–47). The lower division is represented east of the Canal Zone along and near the Transisthmian Highway; the middle division at and near Gatun; and the upper division at Mindi (along the approach to Gatun Locks) and at and near Mount Hope. The middle and upper faunal divisions are more or less transitional, the fossils indicating progressively greater distance off-shore and progressively deeper water upward in the formation. The discontinuity at Gatun Dam spillway, interpreted by Olsson (1942, pp. 244–45) as the unconformity between the Gatun and Caimito formations, is a discontinuity in the middle part of the Gatun formation. Similar minor discontinuities are apparent in the 545 feet of strata of the middle part exposed in the excavation for the Gatun Third Locks.

Only the middle division is recognized southwest of the Canal, but the faunal association changes somewhat. The collections from that area were made by Olsson in 1918 during the course of mapping for the Sinclair Panama Oil Corporation. It is unlikely that Olsson's (p. 246) upper division of the Gatun southwest of the Canal is the equivalent of the upper part of the formation east of the Canal. The regional relations show overlap by the Chagres sandstone southwest of the Canal. Olsson's shallow-water *Anomia* zone is considered part of the Toro limestone member of the overlying Chagres sandstone, as indicated by his Río Piña section (p. 246), not part of the Gatun formation.

A still different faunal association, possibly younger than any in the Canal Zone, is represented along the Caribbean coast between Río Indio and Río Miguel west of the area shown in Figure 1. Some of the collections, all of which were made in 1918 by geologists of the Sinclair Panama Oil Corporation, show faunal similarities with the Chagres sandstone.

The Gatun formation has been considered middle Miocene for many years. It probably represents all of the West Indian middle Miocene. Most of the formation, however, has faunal affinities with West Indian late middle Miocene. The part of the formation along the Caribbean coast west of the Canal Zone may possibly be late Miocene in age, if all the collections of fossils so labelled are from the Gatun formation.

CHAGRES SANDSTONE, INCLUDING TORO LIMESTONE MEMBER

Canal Zone and adjoining part of Panama west of Zone.—The Chagres sandstone crops out in the Canal Zone west of the Canal and extends westward along the Caribbean coast at least as far as the mouth of Río Indio, about 23 miles southwest of Colón. It overlies and partly overlaps the Gatun formation, its base being sharply defined. The name for the formation was proposed by MacDonald (1919, p. 532). The coastal area between Río Chagres and Limon Bay may be considered the type region. The Toro limestone member was also named by MacDonald (1915, p. 26), as a separate formation. The type region is at Toro Point, on the west side of Limon Bay.

The Toro limestone member is a thin basal member of variable thickness, the maximum being 125 feet. It is for the most part a lime-cemented coquina made up of barnacle and shell fragments. Lenses of medium- to coarse-grained sandstone are interbedded with the calcareous beds. The Chagres sandstone proper above the Toro limestone member consists of very massive mostly fine-grained sandstone and some siltstone. It is more massive and generally less fossiliferous than the Gatun formation and, unlike the Gatun, includes no beds of tuff or conglomerate. MacDonald thought its thickness may be as much as 1,000 feet, or even more. It is so massive, however, that the thickness is difficult to determine.

Collections from the Toro limestone member of the Chagres contain about 30 species of mollusks, all except a few of which are Gatun species or are closely related to Gatun species. *Pecten gatunensis macdonaldi*, which is locally abundant, is a form of a Gatun species. *Sthenorytis toroense* has not been found in the Gatun formation. About 50 species are in collections from the Chagres sandstone proper. At least half are Gatun species or closely related forms. *Acila isthmica* is more abundant than in the Gatun formation. Several Chagres species occur elsewhere in formations that are probably late Miocene in age: *Dentalium rimosum*, *Aequipecten cactaceus*, and an apparently undescribed small *Amusium* in Tehuantepec, and *Architectonica karsteni* in Venezuela. The marked Gatun affinities favor a late Miocene age for the Chagres sandstone. It may, however, be early Pliocene if the coastal Gatun west of the Canal Zone is late Miocene. The Pliocene of the Caribbean region is not yet satisfactorily subdivided. Much of what has been assigned to undifferentiated Pliocene is doubtless late Pliocene.

SUMMARY

The Tertiary formations of the Canal Zone and adjoining parts of Panama range in age from late Eocene to late Miocene, or possibly early Pliocene. Only

two main age divisions are recognized in the Oligocene—early and late. At the present time a satisfactory three-fold subdivision of the Caribbean Oligocene is not apparent, at least on the basis of the fossil mollusks and apparently also on the basis of the orbitoids and corals. The Antigua formation of the island of Antigua, formerly considered the standard for the middle Oligocene of the Caribbean region, is now correlated with formations of late Oligocene age in southeastern United States.

The late Eocene Gatuncillo formation is strongly transgressive; the middle and late(?) Miocene Gatun formation is also transgressive; the late Oligocene(?) and early Miocene Culebra formation and the late Miocene or early Pliocene(?) Chagres sandstone represent minor overlaps.

According to the suggested correlations shown in Figure 2, the succession in both Canal Zone areas is incomplete. The only fairly satisfactory post-Eocene faunal correlation is that between the lower member of the Caimito formation in the Gatun Lake area and the Quebrancha limestone member of the same formation in the Quebrancha syncline. The absence of a Culebra fauna in the Caimito formation of Madden basin is a serious handicap in faunal correlations. Perhaps the hiatus between the Las Cascadas agglomerate and Culebra formation is to be eliminated by downward shifting of the Culebra and overlying formations. It appears probable, however, that the equivalent of much of the Caimito formation is overlapped by the Culebra formation, just as the equivalent of the Culebra and overlying formations is probably overlapped by the Gatun formation. An exhaustive study of the tuffaceous constituents of the Tertiary formations, particularly of the Caimito formation, may yield more satisfactory correlations than the faunal correlations now proposed.

If the correlations between the Caribbean and Pacific sides of the Canal Zone shown in Figure 2 are substantiated, it can not be demonstrated from the distribution of the marine formations when, if ever, the present Canal Zone was completely submerged. The marine formations of the Canal Zone were probably deposited in marginal embayments leading from a sea covering a more extensive area east of the Zone, including the present Madden basin. That area may have been the site of a seaway connecting the Caribbean Sea and Pacific Ocean at least during late Eocene, Oligocene, and early Miocene time. However that may be, the main and most persistent marine strait separating North and South America was doubtless farther southeast, along Olsson's Bolívar geosyncline (Olsson, 1932, p. 53). The marked Pacific affinities of the Gatun and Chagres faunas indicate that the Caribbean and Pacific were in free communication somewhere nearby through late Miocene or early Pliocene time.

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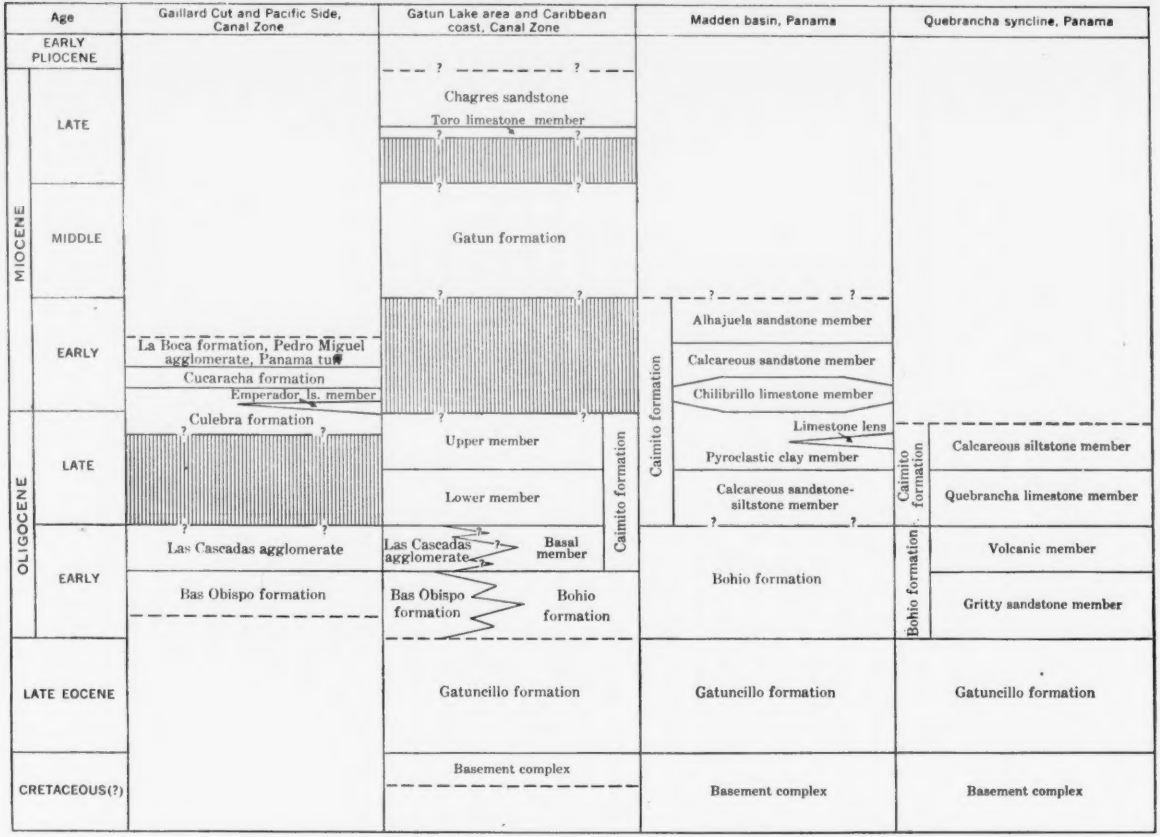

FIG. 2.—Suggested correlations of Tertiary formations in Panama Canal Zone and adjoining parts of Panama. Broken horizontal lines indicate top or base of formation is not exposed. Vertical ruling indicates hiatus; omitted between Gatuncillo formation and basement complex. Age of Las Cascadas agglomerate and Bas Obispo formation is questionable.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

GUIDE BOOK, GEOLOGY OF THE NORTHERN PORTION OF THE APPALACHIAN BASIN, BY THE PITTSBURGH GEOLOGICAL SOCIETY

REVIEW BY S. H. CATHCART[1]
Harrisburg, Pennsylvania

Guide Book, Geology of the Northern Portion of the Appalachian Basin, edited by George C. Grow, Jr. 121 pp., regional maps showing the route, relief, geology, principal structural features and oil and gas fields; geologic strip maps of the Pennsylvania Turnpike; geologic strip map along the Susquehanna and Juniata rivers in the Harrisburg region; structural sections from Pittsburgh to Harrisburg to New York State line; generalized columnar sections for the regions from Pittsburgh to Harrisburg, Harrisburg to New York State line, southwestern New York and Niagara Falls-Rochester area; columnar sections showing stratigraphic position of oil and gas sands of western Pennsylvania; regional stratigraphic charts showing rock system relationships and major facies changes in east-west and north-south directions; 8 maps depicting the glacial history of Lake Ontario; panorama of Niagara Gorge; topographic coverage. Flexible tough-paper cover, spiral ring binder, 8.5×11 inches. Published by the Pittsburgh Geological Society. For sale by George C. Grow, Jr., 545 William Penn Place, Pittsburgh, Pennsylvania. Price, $5.00.

This guide book, a coöperative effort involving numerous individuals and several organizations, was prepared for the mid-year meeting of the American Association of Petroleum Geologists held at Pittsburgh under the auspices of the Pittsburgh Geological Society, October 4–9, 1948. The field excursion was designed to present the major elements of the stratigraphy and structure of the northern part of the Appalachian basin. The basin was traversed in both east-west and north-south directions and the trip as logged afforded an excellent opportunity to view and discuss rock system relationships and facies changes throughout a broad area in which Cambrian, Ordovician, Silurian, and Mississippian rocks are exposed.

Itinerary.—The itinerary of 68 pages is preceded by a 3-page summary or outline of the principal features to be observed on each day of the 3-day excursion.

On the first day the route from Pittsburgh to Harrisburg (229 miles) follows the Pennsylvania Turnpike with one short side trip to a vantage point on the Allegheny Front which affords a view of the Ridge and Valley Province on the east. For the first 90 miles the route crosses the Allegheny Plateau region where gently folded rocks of the coal-bearing Pennsylvanian system are exposed. East of the Allegheny Front the Turnpike crosses the Ridge and Valley region where road cuts afford excellent exposures of highly folded Paleozoic rocks that range in age from Cambrian to Mississippian. From the east terminus of the Turnpike at Carlisle, the route follows the Great Valley to the Susquehanna River at Harrisburg, then north along the west bank of the river for 10 miles to include the Ordovician-Mississippian section exposed where the Susquehanna cuts through the Kittatinny and Cove mountains. The strip map provided for this part of the trip pictures the geology along the Susquehanna and Juniata rivers between Highspire and Half Falls Mountain and includes columnar and structural sections.

[1] Director, Pennsylvania Topographic and Geologic Survey.

On the second day, the country between Harrisburg, Pennsylvania, and Rochester, New York (262 miles), is traversed. The route follows the east side of the Susquehanna River to Sunbury, thence overland to Williamsport and north to enter New York at Lawrenceville. The Allegheny Plateau and Ridge and Valley provinces crossed from west to east on the first day's trip are traversed in reverse order from south to north the second day; at Lake Canandaigua, New York, the route enters the Interior Lowland. On this traverse rocks of Devonian and Mississippian age dominate the scene throughout both the Ridge and Valley and the Plateau terranes. Glacial deposits appear from Sunbury north and, locally, form striking features of the terrane in New York. The flatter-surfaced Interior Lowland is underlain by Silurian and Devonian rocks that dip southward. On the first day's trip the Mississippian, Devonian, Silurian, and Ordovician sediments show important facies changes that reflect an approach toward ancient land areas on the east; on the second day facies changes in part reflect retreat from those land areas.

The third day's itinerary covers a route from Rochester to Niagara Falls and Buffalo (118 miles) that skirts the south shore of Lake Ontario near an escarpment capped by Middle Silurian. Gorges cut in the escarpment by the Genesee and Niagara rivers expose Ordovician and Silurian strata of the northern rim of the Appalachian basin. Devonian is seen at Buffalo. Marked changes in sequence, facies, and thickness are observed between this and the central Pennsylvania region, changes which may have important bearing on prospects for future production of oil and gas in the deeper formations of the Appalachian region.

A supplementary log covering a route from Buffalo to Bradford (92 miles), along which Devonian to Pennsylvanian rocks are exposed, concludes the itinerary.

The itinerary is well executed. It outlines effectively the stratigraphy, structure, and geomorphology of the region. Inserted, too, are pertinent references to points of historic and cultural interest.

From the stratigraphic viewpoint, especially, this publication is more than just a guide book. Appended to the guide book proper is a chapter which is titled, "General Characters of the Paleozoic Sediments from Western to Central Pennsylvania and to Western New York," by Frank M. Swartz. It consists of 20 pages of text and 3 page-size stratigraphic charts which are prepared as cross sections and serve to portray equivalence of facies and stratigraphic names in ready reference form. This chapter is a very able presentation, in outline, of the Paleozoic stratigraphy of this region and should be welcomed by all interested in Appalachian geology.

RECENT PUBLICATIONS

CUBA

*"Quelques Nummulitidés nouveaux ou non encore signalés de l'Éocène de Cuba," by Mme. de Cizancourt. *Bull. Soc. Geol. France*, Ser. 5, Tome 17, Nos. 7–8–9 (Paris. September, 1948), pp. 513–21; 2 pls. 28, rue Serpente 6, Paris.

FRANCE

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*"Étude du Cuisien dans les Vexins français et normand," by L. Feugueur. *Ibid.*, pp. 543–58; 2 figs.

GENERAL

**Emanuel Kayser's Abris der Geologie, Zweiter Band, Historische Geologie*, by Roland Brinkmann. 356 pp., 64 figs., 58 pls., 18 correlation charts. 6.25×9.50 inches. In German.

Ferdinand Enke, 14a Stuttgart W., Hasenbergsteige 3, American Zone, Germany (1948). Price: paper cover, DM 25; clothbound, DM 27.

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KANSAS

*"The Stratigraphy and Structural Development of the Salina Basin of Kansas," by Wallace Lee, Constance Leatherock, and Theodore Botinelly. *Kansas Geol. Survey Bull. 74* (Lawrence, November, 1948). 155 pp., 11 figs., 18 tables, 14 pls.

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MEXICO

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MICHIGAN

"Thickness and Lithology of Upper Ordovician and Lower and Middle Silurian Rocks in the Michigan Basin," by George V. Cohee. *U. S. Geol. Survey Prelim. Chart 33*, Oil and Gas Inves. Ser. (December 31, 1948). 41×50 inches. For sale by Director, U. S. Geological Survey, Washington 25, D. C. Price, $0.75.

MISSOURI

"Geologic Map Index of Missouri," by Leona Boardman and Annabel Brown. One

of a series entitled, "Index to Geologic Mapping in the United States." Scale: 1 inch equals 12 miles. For sale by Director, Geological Survey, Washington 25, D. C. Price, $0.30.

NEW MEXICO

*"Age and Correlation of the Devonian Sly Gap Beds near Alamogordo, New Mexico," by Merrill A. Stainbrook. *Amer. Jour. Sci.*, Vol. 246, No. 12 (New Haven, Connecticut, December, 1948), pp. 765–90; 2 pls. of fossils.

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PERU

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TEXAS

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TURKEY

*"Relations entre Tectonique et Seismicité en Turquie," by Ervin Lahn. *Bull. Soc. Geol. France*, Ser. 5, Tome 17, Nos. 7–8–9 (Paris, September, 1948), pp. 493–502; 1 fig. 28, rue Serpente 6, Paris.

UTAH

"Geologic Map Index of Utah," compiled by Leona Boardman. One of a series entitled, "Index to Geologic Mapping in the United States." Scale: 1 inch equals 12 miles. For sale by Director, Geological Survey, Washington 25, D. C. Price, $0.25.

VENEZUELA

*"Stratigraphy and Fauna of the Agua Salada Group, State of Falcón, Venezuela," by H. H. Renz. *Geol. Soc. America Mem. 32* (New York, December 10, 1948), 219 pp., 12 pls. of foraminifera, 15 figs., 19 tables.

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"A Cephalopod Fauna from the Type Section of the Pennsylvanian 'Winslow Formation' of Arkansas," by A. K. Miller and R. H. Downs.

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"Studies in Quantitative Paleontology: I. Some Aspects of the Theory and Practice of Quantitative Invertebrate Paleontology," by Benjamin H. Burma.

"Eocene Algae from Florida," by J. Harlan Johnson and Bernard J. Ferris.

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*Terms of individuals expire at the close of the annual meeting in March of the year indicated, unless another month is shown.

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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(Continued on p. 269)

JOINT ANNUAL MEETING, ST. LOUIS, MARCH 14–17, 1949

ANNOUNCEMENT

This is the 34th annual meeting of the A.A.P.G., the 23d annual meeting of the S.E.P.M., and the 19th annual meeting of the S.E.G. Announcement of this joint meeting was mailed to each member in July, 1948, and subsequent notices have been published periodically.

HOTEL ROOMS

Members who have not requested reservations should no longer postpone their plans. Use the required form, "Application for Housing Accommodations," which must be sent to the A.A.P.G. Hotels Reservation Bureau, 1420 Syndicate Trust Building, St. Louis 1, Missouri. This form was mailed to each member last July. These hotels are now filled: Jefferson, Statler, ——

PAPERS

The technical program covering the four days is arranged in full.

MONDAY, March 14, is the day of business and other committee meetings for the A.A.P.G., and a technical session for the S.E.G. On Monday night, the A.A.P.G. research committee holds its popular annual open meeting—this year on "Control of Petroleum Accumulation by Sedimentary Facies."

TUESDAY, March 15, is the joint meeting day: presidential addresses and special

awards in the morning, and papers of common interest to the three societies in the afternoon. Tuesday evening is open for entertainment as the individual may choose from the ample variety offered in St. Louis.

WEDNESDAY, March 16, is the day of concurrent meetings. In the forenoon, A.A.P.G. presents statistics of exploratory drilling and field papers on new types of reservoirs; in the afternoon, a symposium on "Reefs." S.E.G. resumes its technical sessions. S.E.P.M. presents a symposium on the "Quaternary of the Gulf of Mexico" in the morning, and meets with the A.A.P.G. for the symposium on "Reefs" in the afternoon.

On THURSDAY, March 17, A.A.P.G. has a forenoon program on areas outside the United States, and a list of miscellaneous subjects in the afternoon, followed by the annual business meeting. S.E.P.M. has a symposium on "Fundamental Problems in Paleontology." S.E.G. has no papers scheduled, but offers trips to local educational and scientific institutions.

On Thursday night, the dinner-dance.

ENTERTAINMENT

The annual semi-formal dinner-dance is to be held on Thursday night, March 17, the last night of the meeting, in the Gold Room of the Jefferson Hotel. Tickets will be sold at the registration counter; after your arrival, be sure to purchase before Thursday; the price is $6 per person.

Ladies attending the convention will find a convenient Gray Line information desk on the Jefferson Hotel Mezzanine where an attendant will assist in the selection of city sightseeing trips.

FIELD TRIP

The Missouri Geological Survey and the Illinois Geological Survey are cooperating to arrange a geological field trip on Friday and Saturday, March 18 and 19, following the convention, from St. Louis south to Cape Girardeau and return, down one side of the Mississippi and back on the other side. Exposures of Paleozoic rocks will be visited under able guidance. Transportation will be in chartered buses.

EXHIBITS

Methods and equipment used in exploration for petroleum will be displayed on the Jefferson Hotel Mezzanine. Space is sold out.

Educational map and chart displays of government surveys, colleges, and societies will be arranged on the Second Floor of the Jefferson. Space is free but restricted to new or significant material of interest. Requests for space should be directed to A.A.P.G., Box 979, Tulsa 1, Oklahoma.

OUTLINE OF EVENTS

SUN., MARCH 13	Registration
MON., MARCH 14	
A.M. and P.M.	A.A.P.G. Business and other committees. S.E.G. Technical sessions.
Night	A.A.P.G. Research committee open session. "Control of Petroleum Accumulation by Sedimentary Facies."
TUES., MARCH 15	
A.M.	Joint session. Presidential addresses and awards
P.M.	Joint session. General papers
WED., MARCH 16	
A.M.	A.A.P.G. Exploratory drilling and field papers S.E.G. Technical sessions S.E.P.M. "Quaternary of the Gulf of Mexico"
P.M.	A.A.P.G. Symposium on "Reefs" S.E.G. Technical sessions
Night	Address: "Atomic Energy in Relation to Geology," Sumner T. Pike, U.S. Atomic Energy Commission.

THURS., MARCH 17	
A.M.	A.A.P.G. Foreign papers
	S.E.P.M. "Fundamental Problems in Paleontology"
P.M.	A.A.P.G. Miscellaneous papers
	Annual business meeting
	S.E.P.M. Technical session
Night	Annual dinner-dance
FRI.-SAT., MARCH 18–19	Field trip

SPECIAL TRAIN FROM TEXAS

The Houston Geological Society, with the cooperation of the Dallas Geological Society and the Fort Worth Geological Society, is sponsoring a round trip Special Train to the 34th annual meeting of the A.A.P.G., and to the S.E.G. and S.E.P.M., in St. Louis, Missouri, March 14–17. The special train, with members aboard from the Southwest Mid-Continent region, will leave Houston over the Southern Pacific-M.K.T.-Frisco Lines Saturday, March 12, at approximately 1:00 P.M., and is scheduled to arrive in St. Louis, Missouri, Sunday, March 13, at 11:25 A.M. Special cars from other points in Texas will be picked up at Dallas. Printed itineraries, giving detailed schedules of trains making connections with the special train, are being mailed to members living in Texas and parts of Louisiana.

It is the intention of the societies to run a special train from St. Louis back to Dallas and Houston. This train is scheduled to leave St. Louis, Friday morning, March 18 at 11:00 A.M. Cars will be set off in Dallas for occupancy until 8:30 A.M. The return special train is scheduled to arrive in Houston at 9:30 A.M., March 19.

It is suggested that those receiving the printed itinerary discuss with their local ticket agent the purchase of tickets to Dallas or Houston, the main assembly points. The figure given in the itinerary for round trips from Dallas to Houston should be used. For example, a round trip first-class ticket from Houston to St. Louis including 15% federal tax and lower berth to and from St. Louis will cost $76.00. A round trip first-class ticket from Dallas to St. Louis including 15% federal tax and lower berth to and from St. Louis will cost $63.35. Compartment, bedroom, or drawing-room accommodations will be slightly higher in cost. Fares from all principal points will be quoted in the printed itinerary which is being mailed.

It should be emphasized that no one connected with the special train has any connections with the St. Louis Hotel Reservations Committee of the A.A.P.G., S.E.G., and S.E.P.M. Individual members should continue to make St. Louis hotel reservations through the Hotels Reservations Bureau, A.A.P.G. Convention, 1420 Syndicate Trust Building, St. Louis, Missouri.

It is suggested that all members read the joint meeting announcement in this issue of the *Bulletin* for all details pertaining to St. Louis hotel reservations. A hotel room reservation form has been mailed each member for return to the St. Louis committee.

The special train itself will be limited to approximately sixteen cars, and any overflow or late reservations will move on the regularly scheduled M.K.T.-Frisco trains unless enough reservations are sold for a second section. A positive guarantee has been received from the M.K.T.-Frisco Lines that the second section of the train will carry full car lounge equipped with piano, two dining cars (should the number of reservations warrant) and as good quality of Pullman cars as those attached to the first section.

It is therefore important that each person mail check for Pullman space with reservation requests if accommodations are desired on the special train or trains.

The Houston, Dallas, and Fort Worth geological societies extend a cordial invitation to all members of the A.A.P.G., S.E.G., and S.E.P.M. living in the Southwest to join them on this round trip special train.

CARLETON D. SPEED, JR.
In charge of special train

(This is a copy of the form which has been mailed to members, last July. If needed, extra copies may be obtained from A.A.P.G. headquarters, Box 979, Tulsa, Oklahoma. The following hotels are already booked to capacity: Jefferson, Statler, etc.

APPLICATION FOR HOUSING ACCOMMODATIONS, ST. LOUIS, MO.

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS—MARCH 14–17, 1949

For your convenience in making hotel reservations for the coming joint meeting of the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, and the Society of Exploration Geophysicists, March 14–17, 1949, in St. Louis, hotels and their rates are listed below. Use the form at the bottom of this page, indicating your first, second and third choice. Because of the limited number of single rooms available, you will stand a much better chance of securing accommodations if you request calls for rooms to be occupied by two or more persons. All reservations must be cleared through the housing bureau. ALL REQUESTS FOR RESERVATIONS MUST GIVE DEFINITE DATE AND HOUR OF ARRIVAL AS WELL AS DEFINITE DATE AND APPROXIMATE HOUR OF DEPARTURE, ALSO NAME AND ADDRESSES OF ALL PERSONS WHO WILL OCCUPY RESERVATIONS REQUESTED *must* BE INCLUDED.

Hotel	*For One Room*	*For Two Persons*		*2-Room Suites*
		Double Bed	*Twin Beds*	*Parlor and Bedroom*
BALTIMORE	2.75–3.50	3.75– 4.50	4.00– 5.00	
CLARIDGE	3.00–4.00	4.00– 6.50	5.00– 6.50	10.00 & Up
*DESOTO	2.75–7.00	4.00– 7.00	6.00–12.00	10.50–12.00
*JEFFERSON	3.50–6.00	5.00– 7.00	7.00– 8.00	14.00–22.00
*LENNOX	3.25–6.00	5.00– 6.50	6.00– 8.00	11.00
*MAJESTIC	2.25–3.50	3.00– 4.00	5.00	
*MARK TWAIN	3.00–3.50	4.50– 5.00	5.00– 5.50	
*MAYFAIR	3.25–7.00	5.00– 8.00	6.00– 8.00	10.00 & Up
MELBOURNE	3.50–6.00	5.50– 6.50	6.00– 8.50	12.00–15.50
SHERATON	3.50–6.00	5.25–10.00	5.50–11.00	8.50–15.00
*STATLER	3.50–6.00	5.25– 8.00	7.25–10.00	16.00–19.00

* Downtown

In the event that the hotel room rate structure is changed prior to the above convention, these rates will be changed accordingly.

ALL RESERVATIONS MUST BE RECEIVED PRIOR TO February 14, 1949
American Association of Petroleum Geologists
Hotels Reservation Bureau
1420 Syndicate Trust Building
St. Louis 1, Mo.

Please reserve the following accommodations for the: Joint convention of the A.A.P.G., S.E.P.M., and S.E.G., in St. Louis, Missouri, on March 14–17, 1949

Single Room..... Double Bedded Room..... Twin Bedded Room.....
2 Room Suite..... Other Type of Room.....
Rate: From $..... to $.....

First Choice Hotel.....
Second Choice Hotel.....
Third Choice Hotel.....

Arriving at Hotel (date)..... hour .....A.M. .....P.M. .....
Leaving (date)..... hour .....A.M. .....P.M. .....

THE NAME OF EACH HOTEL GUEST MUST BE LISTED. Therefore, please include the names of *both* persons for *each* double room or twin bedded room requested. Names and addresses of all persons for whom you are requesting reservations and who will occupy the rooms asked for:

.....
.....
.....
.....

(Individual Requesting Reservations)
Name.....
Address.....
City and State.....

If the hotels of your choice are unable to accept your reservation the Housing Bureau will make as good a reservation as possible elsewhere providing that all hotel rooms available have not already been taken.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 2 (FEBRUARY, 1949), PP. 260-262, 1 FIG.

MEMORIAL

WILLIAM HARVEY EMMONS
(1876–1948)

During the early evening of November 5, 1948, death came to William Harvey Emmons, one of America's outstanding scientists and teachers. He died suddenly, as he would have desired, at his home in Minneapolis, at the age of 72.

Dr. Emmons was born in Mexico, Missouri, on February 1, 1876. He was graduated from Central College, Fayette, Missouri, in the class of 1897 and then entered the University of Chicago for graduate work in geology. There he served as a fellow in the geology department and acted as research assistant to Dr. Thomas C. Chamberlin who was famous for his researches on cosmology, and on the origin of the solar system. He received his Ph.D. degree at the University of Chicago in 1904 and then joined the United States Geological Survey and worked as a field geologist in some of the famous old mining camps of the west.

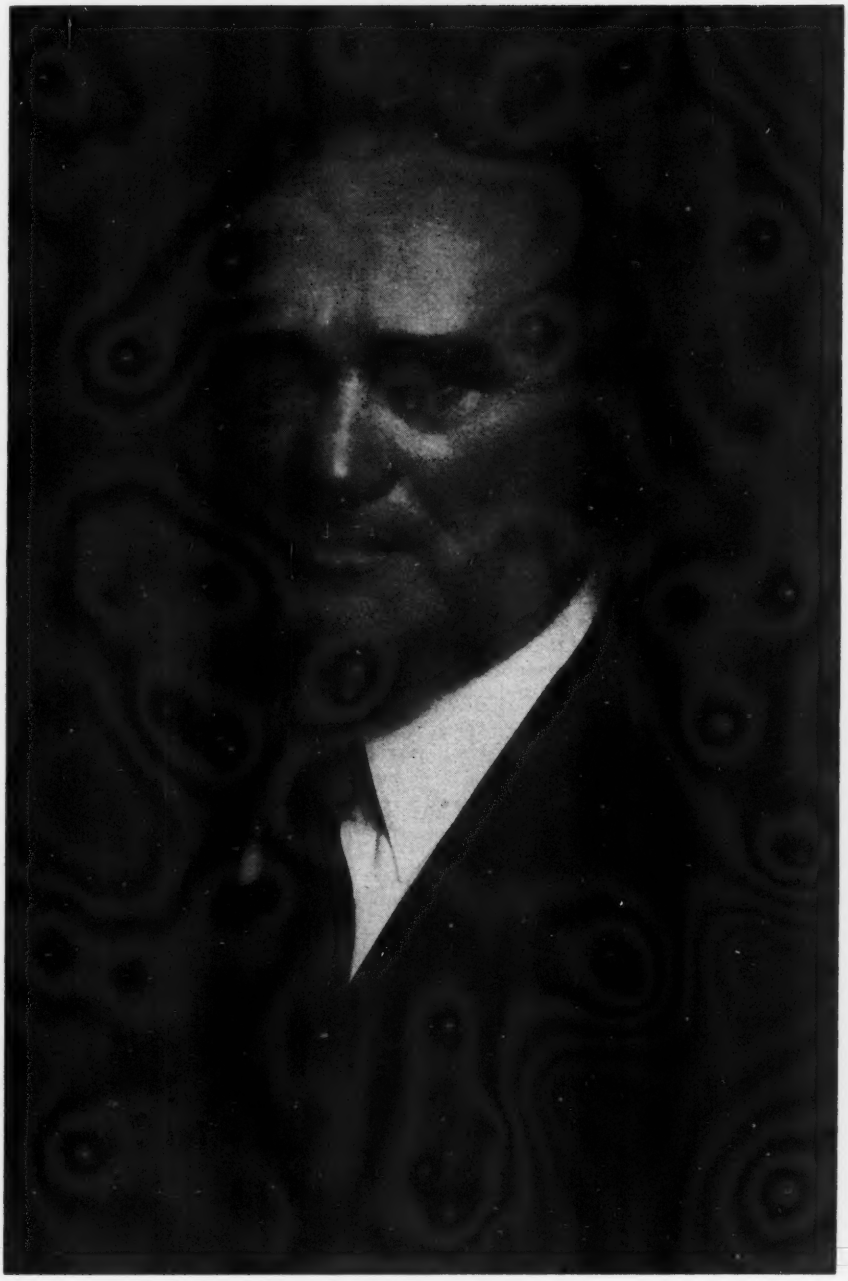
Before leaving the University of Chicago, he married Miss Virginia Cloyd, an able, vivacious, and attractive woman who survives him. Their daughter Betsy, now Mrs. B. E. Mintz, lives in New York City, and a son, William, Jr., is a graduate student in chemistry at the University of Illinois.

Dr. Emmons began his career as a college teacher at the University of Chicago in 1907 and rose to associate professor in 1911. He was then called to the University of Minnesota to become head of its geology department and director of the Minnesota Geological Survey. He held this dual position until his retirement in June, 1944. During the thirty-four years that he served the University of Minnesota, he was a prodigious worker. His researches in collaboration with assistants and students resulted in the publication of a number of textbooks and numerous articles for scientific journals.

Two major research projects held his attention for many years. The first was a study of the secondary enrichment of metalliferous deposits. The results of these studies were published in 1917 as *Bulletin 625* of the United States Geological Survey. This was followed by a broader investigation of the origin of primary metalliferous ore deposits and their occurrence with relation to igneous rock bodies. This second study led to the development of the theory of the zonal arrangement of lode deposits throughout the world. His general conclusions regarding the interrelation of metalliferous ores have been accepted by many economic geologists, and they have served as an aid in exploration. His latest contribution to the problems of ore deposits was the book on *Gold Deposits of the World* published in 1937.

His interest in teaching led directly to the preparation of textbooks on the subjects he taught. *Principles of Economic Geology* was his first book and with Lindgren's *Ore Deposits*, it was used for many years as a standard text for a study of metalliferous ores. In 1932 he collaborated with other members of his staff at the University of Minnesota and published *Geology: Principles and Processes*, a textbook for beginning students of geology. The book had a gratifying reception in numerous colleges and universities.

But excellent research, writing and teaching of ore deposits were not his only achievements. Early in his career he developed a genuine interest in petroleum geology, and he joined our Association in 1919. A few years later he published his textbook, *The Geology of Petroleum*, which during the past 25 years has had great influence in the development of petroleum geology as a phase of economic geology. A measure of the esteem in which he was held by petroleum geologists is evidenced by the fact that the Association conferred upon him the title of Honorary Member at the annual meeting in Chicago in 1946.



WILLIAM HARVEY EMMONS

Other honors were given him at an earlier date. In 1928 he was elected president of the Society of Economic Geologists, and in 1942 that society chose him as recipient of the Penrose Medal, an honor seldom bestowed and now held by only a few living men. In 1921 he was a member of a commission of six who made a study for the Southern Manchurian Railway of the Anshan Steel Works and Fushun Collieries. He was also asked to do consulting work in Mexico, Canada, and Argentina.

Dr. Emmons' intense enthusiasm for all things geological made a profound impression upon his students. His lectures were typical of the man, and he was able to transfer his enthusiasm to the students in the classroom and in the field. Although a specialist in his own field, he was ever aware of the value of a broad background in earth sciences for his students. This conviction is expressed in the following quotation from his acceptance speech at the time the Penrose Medal was conferred upon him.

> There is, however, a very thin line that separates the general geologist from the economic geologist. The successful economic geologist must be one who is first of all a good general geologist—one experienced in the fields of structural geology of stratigraphy, of general geology and of petrology in its widest sense, with an understanding of igneous, sedimentary and metamorphic rocks. To this he adds a knowledge of the geology of metalliferous ores or of petroleum, or of some other special group of deposits.

More than 600 of his students are now professional geologists, and all would agree that he always had a sincere desire to aid them in establishing a successful career in geology. Furthermore, the warm personal ties he developed with scores of his former students show that he placed a lasting stamp of his personality upon them.

Dr. Emmons was a familiar and beloved figure; on the campus or at scientific meetings, everyone knew him or knew who he was. He had a fine sense of humor, witty, friendly, and delighted to spin yarns about his experiences in the mining camps of the west. His career had many facets, but the most brilliant reflections came from his achievements as a teacher and research worker and from the facet that showed him to be a magnificent character, a sympathetic, kindly, and able man.

GEORGE A. THIEL

Minneapolis, Minnesota
December 22, 1948

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 2 (FEBRUARY, 1949), PP. 263-274

AT HOME AND ABROAD

NEWS OF THE PROFESSION

The following persons have been elected officers of the Dallas Geological Society, Dallas, Texas, for 1949: president, JOHN T. ROUSE, Magnolia Petroleum Company; vice-president, H. V. TYGRETT, Atlantic Refining Company; secretary-treasurer, GILBERT P. MOORE, consultant, 501 Continental Building; member of executive committee, EDGAR KRAUS, Atlantic Refining Company.

CHARLES GILL MORGAN, consulting geologist, announces the opening of offices at 1702 Tower Petroleum Building, Dallas, Texas.

PAUL BUTTERMORE has left the Danciger Oil and Refining Company to join the United States Bureau of Mines, Washington, D. C. He will be on the staff of the petroleum economics branch.

IRA H. CRAM, manager of exploration for the Pure Oil Company, Chicago, has been appointed vice-president in charge of exploration for the Continental Oil Company, Ponca City, Oklahoma.

GLENN C. CLARK, formerly chief geologist for the Continental Oil Company, has been appointed senior staff geologist.

J. A. CULBERTSON is chief geologist of the Continental, Ponca City, Oklahoma.

S. K. CLARK is coördinator of exploration activities of the Continental.

At the December 7, 1948, meeting of the Michigan Geological Society, RICHARD A. SMITH, State geologist of Michigan from 1919 to 1946, gave a history of geologic studies of Michigan in his talk, "From Houghton to Eddy," and was presented with a certificate of honorary life membership in the Society.

J. W. BOWLER, formerly with the Colombian Petroleum Company at Cuenta, Colombia, is now with the Socony-Vacuum Oil Company, Inc., 62 Shariah Ibrahim Pasha, Cairo, Egypt.

EARL M. STILLEY, independent geologist, Wichita Falls, Texas, died on December 27 at the age of 48 years.

GEORGE G. SIMPSON, American Museum of Natural History, spoke on "Continents in the Age of Mammals," before the Tulsa Geological Society, January 3.

E. L. SELK, Stanolind Oil and Gas Company, Oklahoma City, spoke on "Problems of the Mayes in Oklahoma," before the Tulsa Geological Society luncheon meeting, January 7.

New officers of the Kansas Geological Society, Wichita, Kansas, are: president, DON W. PAYNE, Sinclair Prairie Oil Company; vice-president, T. G. WRIGHT, Stanolind Oil and Gas Company; secretary-treasurer, VICTOR F. REISERER, Superior Oil Company.

LYNN K. LEE, assistant to the manager of the Texas producing division of the Pure Oil Company, at Fort Worth, has been named manager of exploration for the company to succeed IRA H. CRAM who resigned to become a vice-president of the Continental Oil Company at Ponca City, Oklahoma.

The American Institute of Mining and Metallurgical Engineers will hold its annual 1949 meeting in San Francisco, February 13–17.

SAMUEL P. ELLISON, JR., formerly district geologist for the Stanolind Oil and Gas Company at Wichita Falls, Texas, has joined the Staff of the University of Texas as professor of geology and consultant to the Bureau of Economic Geology and University Lands.

J. T. MCGLOTHLIN, zone geologist for the Gulf Refining Company at Laurel, Mississippi, has resigned to become a consultant at Laurel.

The Pacific Section of the Association plans to hold its annual fall meeting on November 17 and 18, 1949, at the Ambassador Hotel, Los Angeles, California.

P. N. GLOVER has been employed as engineer trainee in the exploitation engineering division of the Shell Oil Company of California. He recently graduated with a degree in geology from the California Institute of Technology.

RALPH S. COOLEY is returning to Midland, Texas, to enter private consulting practice, specializing in handling leases and mineral interests.

RICHARD V. HUGHES has resigned his position as director of production research for the Pennsylvania Grade Crude Oil Association at Bradford, Pennsylvania, to accept a research and teaching position at the Standard Research Institute, Palo Alto, California.

J. BRIAN EBY, consulting geologist of Houston, is elected president of the Texas Academy of Science, succeeding L. W. BLAU of the Humble Oil and Refining Company. W. ARMSTRONG PRICE, consultant of Corpus Christi, is elected to the board of directors.

M. KING HUBBERT, of the Shell Oil Company, Houston, Texas, spoke on "Motion of Ground Water," at the meeting of the Shreveport Geological Society, Shreveport, Louisiana, December 20.

P. E. NARVARTE, consulting geophysicist, has moved his office from the Insurance Building to the American Hospital and Life Building, Houston, Texas.

The Coastal Geological Society held a meeting at Eaton's Restaurant in Santa Barbara, California, on October 11, 1948. E. R. ORWIG, of General Petroleum Corporation, talked on "The Vaqueros Formation in the Santa Barbara Area." A paper on the "History and Development of the Cuyama Valley," given by HERMAN SCHALLER, of Eastern Oil Well Surveying Company, was entitled "Some Aspects of Directional Drilling."

At the regular monthly meeting, October 5, at the El Tejon Hotel, Bakersfield, California, the San Joaquin Geological Society elected the following new officers: ROBERT B. HUTCHESON, president; FLOYD L. JOHNSON, vice-president; and MAXWELL G. CAPEN, secretary-treasurer.

JAMES E. CLARK, formerly with the Bay Petroleum Corporation, is with the Ohio Oil Company, Wichita, Kansas.

R. A. SHELDON has been transferred from the Tropical Oil Company, Bogota, Colombia, to the Standard Vacuum Petroleum Maatschappij in the East Indies. He may be addressed in care of S.V.P.M. Soengei Gerong, Palembang, Sumatra.

T. L. STALL has resigned from the Shell Oil Company to be district geologist for the Cabot Carbon Company, Midland, Texas.

ALFRED K. TYSON has changed his address from the Barber Asphalt Corporation to the American Republics Corporation, Houston, Texas.

ORLO E. CHILDS has accepted a position with the Phillips Petroleum Company at Salt Lake City, Utah.

E. E. SCHIECK has resigned his position as geologist with the Sohio Petroleum Company to accept a position with the Morton Oil Company, Casper, Wyoming.

GEORGE Y. MCCOY, formerly with the Republic National Bank of Dallas, Texas, announces the opening of offices for the consulting practice of petroleum engineering and geology, in the Empire Bank Building, Dallas.

LEROY A. WOOLLETT is employed in the engineering department of the Magnolia Petroleum Company at Brownfield, Texas.

E. O. BUCK is a vice-president of the National Bank of Commerce, Houston, Texas.

P. L. KELLER, consulting geologist, may be addressed at Box 985, Denver, Colorado.

ARTHUR RAYMOND MAY, chief geologist of the Superior Oil Company, died at Los Angeles, California, December 9, 1948, at the age of 55 years. The cause was a heart attack.

PAUL WEAVER continued his presidential tours of the affiliated societies and other groups of geologists in January, talking on "Continental Shelves," and discussing affairs of the A.A.P.G. From January 10 to 20 he spoke at Shreveport, Louisiana; Evansville, Indiana; Ann Arbor and Lansing, Michigan; and San Antonio, Texas.

Newly elected officers of the Panhandle Geological Society, Amarillo, Texas, are: president, G. E. HATTON, Phillips Petroleum Company; vice-president, ROBERT F. HERRON, Oil Development Company; secretary-treasurer, ROBERT B. TOTTEN, Sun Oil Company.

E. G. DAHLGREN, Assistant Secretary of the Interstate Oil Compact Commission, has resigned, effective January 1, to become a consultant in the Braniff Building at Oklahoma City, Oklahoma.

ERNEST R. LILLEY has been elected vice-president in charge of the Great Lakes Carbon Corporation's oil and gas division. For several years manager of the division, he continues as its chief geologist and makes his headquarters at the Corporation's New York general office.

J. BEEBE THOMPSON, authority on world oil, spoke on "Oil Developments in the Middle East," before the Houston Geological Society, January 10.

JOHN H. FETH, of the department of geology and geography, University of Arizona, Tucson, was elected president of the Arizona Geological Society for 1949.

The Rocky Mountain Association of Geologists, Denver, Colorado, has elected officers for 1949: president, DART WANTLAND; 1st vice-president, STANLEY W. LOHMAN; 2d vice-president, E. W. SCUDDER; secretary-treasurer, KENNETH GOW; and councillors-at-large, H. W. C. PROMMEL and A. RICHARD WASEM.

W. PETRASCHECK, head of the department of geology, Mining University of Leoben, Austria, was honored by the gold medal of the Gesterreichische Ingenieur und Architekten Verein at its 100-year jubilee.

Four $1,000 graduate fellowships leading to the master's degree at the University of Wichita for the academic year 1949–1950 are being offered by the University of Wichita Foundation for Industrial Research to stimulate graduate study and to encourage industrial research. One of these awards will be made in the field of petroleum geology to a graduate of an accredited college or university. It will be made on a basis of merit and will carry a stipend of $1,000 plus tuition and fees. The university will provide additional remuneration for any part time teaching or assisting which may be required. The only restriction is that the thesis subject must pertain to problems which are of importance to the Wichita area. Full information on the awards may be obtained from the chairman of the committee on scholarships and student aid, University of Wichita, Wichita 6, Kansas.

F. HOWARD BRADY, 1951 South Chestnut, Casper, Wyoming, has resigned as geologist with the Chemical and Geological Laboratories to return to consulting and independent geological work with headquarters at his Casper address. He has served in this capacity in the Rocky Mountain area since 1936. He has entered into partnership with C. Byron Elmgren of Sheridan, Wyoming.

J. W. BARBISCH has left the Petty Geophysical Engineering Company and is now connected with the Quintana Petroleum Corporation at Houston, Texas.

E. GLENN ALBRIGHT has left the Atlantic Refining Company to become a seismologist with the Richmond Exploration Company. His address is Apartado 93 c/o Rexco, Maracaibo, Venezuela.

W. F. ROGERS is with W. C. McBride, Inc., Lander, Wyoming. He was formerly in the employ of the Carter Oil Company.

WEST TEXAS GEOLOGICAL SOCIETY FIELD TRIP NOVEMBER 6–9, 1949

In connection with the 62d annual meeting of the Geological Society of America at El Paso, Thursday through Saturday, November 10, 11, and 12, 1949, the host society, the West Texas Geological Society, is sponsoring five field excursions to study various phases of the geology of western Texas and of New Mexico. Each of these excursions will be four days in length, beginning Sunday morning, November 6, and ending Wednesday evening, November 9, in El Paso. Chairman of the field-trip committee is John M. Hills. Chairman in charge of arrangements and transportation is W. Dave Henderson. Though parts of each excursion may appear to overlap, the excursions are so planned as to interest the students of various geological specialties, and the features pointed out on the route will be different for each trip. Transportation by bus or private car will be furnished from the assembly point to El Paso on each trip. It is requested that Fellows and Members of the Society who intend to bring their cars indicate this, as well as their choice of trips.

EXCURSION I

PETROLOGY AND IGNEOUS GEOLOGY OF BIG BEND AREA

Registration limited to 50 geologists
Leaders: John T. Lonsdale, Ross A. Maxwell, S. S. Goldich, and J. Fred Smith, Jr.
Vice-Chairman of Arrangements and Transportation: Robert E. LeBlond

The party will assemble at Marathon, Texas, Saturday evening, Nov. 5, 1949, and will leave Marathon early Sunday morning, Nov. 6, 1949, and drive to the Big Bend National Park headquarters. The party will have a general view of the Marathon Paleozoic folds

and will study the Cretaceous rocks into which the intrusives were placed. They will spend Sunday night at the Basin Lodge in Big Bend National Park. Monday, the party will study the Chisos Mountains and the related intrusives. They will see the Santa Elena Canyon, a spectacular gash cutting through a large fault block of Cretaceous limestone by the Rio Grande. They will sample and study the relationships of numerous analcite-bearing intrusives. Monday night will be spent at the Basin Lodge also. On Tuesday the party will drive northwest out of the park area to the old quicksilver mines at Study Butte and Terlingua. On Tuesday afternoon they will see the extrusive Tertiary volcanics and tuffs in Green Valley, south of Marfa. Tuesday night will be spent at Marfa. Wednesday the party will drive from Marfa to Sierra Blanca and then southwest through the Quitman Mountains to study the Quitman pluton and related volcanics. The excursion will arrive in El Paso on Wednesday afternoon.

EXCURSION II

CENOZOIC GEOLOGY OF LLANO ESTACADO AND RIO GRANDE VALLEY

Leaders: Glen Evans, Charles B. Read, Vincent Kelley, Georges Vorbe, and W. S. Strain
Vice-Chairman in charge of Arrangements and Transportation: L. E. Patterson

The party will assemble at Lubbock on Saturday evening, Nov. 5, 1949, and leave Lubbock early Sunday morning, Nov. 6, 1949, stop at prolific vertebrate site on the north side of Lubbock and then proceed southwest to Rich Lake, the large playa where the processes of playa deposition can be seen. Then the party will proceed north and east to Yellow House Canyon, where relationship of the Pliocene to the Pleistocene will be studied. Then the excursion will go north and east to White River Canyon, where the type locality of the Blanco may be seen. Plainview will be reached in the late afternoon and an early-man locality on the northern edge of town will be examined. After dinner at Plainview the party will drive to Clovis. The excursion will leave Clovis early Monday morning, Nov. 7, 1949, for Santa Fe. One stop will be made to view the northwestern side of the Llano Estacado deposits and other stops will be made to view the various erosional surfaces in the area south of Santa Fe. The party will spend the night at Santa Fe. Tuesday the party will study the Santa Fe formation and related deposits in the vicinity of Santa Fe and will stay at Socorro on Tuesday night. On Wednesday, Nov. 8, the party will drive to El Paso making a side trip to study Kilbourne hole, a volcanic west of Las Cruces and arrive in El Paso *late* Wednesday afternoon.

EXCURSION III

CENTRAL MINING DISTRICT, NEW MEXICO

Leaders: Irvin Gladstone and members of the Southwestern New Mexico Section of the A.I.M.E.
Vice-Chairman in charge of Arrangements and Transportation: The same

This trip will study the various types of mineralization in this interesting and compact mining district. The mineralization ranges from disseminated copper porphyry ores through high-temperature magnetite replacements in limestones to low-temperature lead and zinc ores. The party will assemble in Silver City at noon on Sunday, Nov. 6, 1949. Transportation will be furnished from the Southern Pacific Railroad at Lordsburg and at Deming on Sunday morning. Sunday afternoon the party will inspect a very fine unaltered Paleozoic section exposed on the west side of Mimbres Valley. Monday morning, Nov. 7, will be occupied with underground trips in some 14 local mines. Of course, every-

one will not be able to see the same type of mineralization, but a wide variety of types will be available for inspection. Monday afternoon, the party will see the magnetite deposits and altered rocks around Fierro. Monday night, the party will stay in Silver City again. All day Tuesday, Nov. 8, will be devoted to inspection of the Santa Rita open pit of the Kennecott Copper Company where copper porphyry ores are being mined on a large scale. The party will also inspect extensive leaching operations on the waste dumps of this pit and will see the concentrator and smelter operating on these ores. Wednesday, Nov. 9, the excursion will leave Silver City for El Paso, stopping to inspect manganese mines at Silver City and Deming. The excursion should arrive in El Paso early Wednesday afternoon.

EXCURSION IV

PERMIAN ROCKS OF TRANS-PECOS REGION

Leader: J. E. Adams
Vice-Chairman of Arrangements and Transportation: Ed. L. Reed

The party will assemble at Alpine, Saturday night, Nov. 5, and leave Alpine on Sunday morning to spend the day studying the Marathon folds southeast of Alpine and the type sections of the Permian exposed in the Glass Mountains. The party will drive from the Glass Mountains to Pecos for dinner and then from Pecos to Carlsbad to spend the night, Nov. 6. Monday morning will be spent inspecting the potash mines in the Upper Permian salt, and Monday afternoon, Nov. 7, in Carlsbad Caverns. Monday night will be spent at Carlsbad. Tuesday the trip will take the party across the Guadalupe Mountains where opportunity will be had to inspect the Capitan and related Upper Permian beds. Tuesday afternoon, the Lower Permian section in the Diablo front will be studied. The excursion will stay at Van Horn Tuesday night, Nov. 8. On Wednesday the party will drive up the west side of the Diablo Mountains to see Apache or Victorio Canyon from the upper end. Then they will proceed to Sierra Blanca and north to El Paso-Carlsbad highway, stopping to study the Hueco Lower Permian section on the way to El Paso Wednesday afternoon, Nov. 9.

EXCURSION V

PRE-PERMIAN ROCKS OF TRANS-PECOS AREA AND OF SOUTHERN NEW MEXICO

Leaders: P. B. King, L. R. Laudon, Arthur L. Bowsher
Vice-Chairman in charge of Arrangements and Transportation: Clyde W. Turner

The party will assemble in Alpine, Saturday evening, and will leave Alpine on Sunday morning and spend the entire day studying the early Paleozoic rocks in the Appalachian-type folds of the Marathon basin. The party will have dinner at Alpine and drive to Van Horn to stay, Sunday night, Nov. 6. Monday morning, Nov. 7, they will leave Van Horn, visit the exposures of the Cambrian and Ordovician in Beach Mountain north of Van Horn, and then drive west of Van Horn to inspect the pre-Cambrian exposures north of the Texas Pacific Railroad at Allamoore. Then the excursion will drive west to see exposures of El Paso Ordovician limestones. Then they will proceed to Sierra Blanca and north to the El Paso highway, seeing good exposures of the early Paleozoic along the road. In the Hueco Mountains there will be an opportunity to study a section of the Devonian, Mississippian, and basal Pennsylvanian. Monday night, Nov. 7, will be spent in El Paso. Tuesday, the party will drive from El Paso to Alamogordo and will spend Tuesday afternoon and Wednesday morning inspecting the fine Paleozoic section exposed in the western face of the Sacramento Mountains. They will stay at Alamogordo on Tuesday night, Nov. 8, and drive to El Paso on Wednesday afternoon, Nov. 9.

ADDITIONAL APPLICATIONS APPROVED FOR PUBLICATION

(Continued from page 256)

FOR ACTIVE MEMBERSHIP

Erwin Walter Clark, Rio Vista, Calif.
A. J. Solari, W. F. Barbat, George M. Cunningham
Joseph Milton Marsh, Talara, Peru, S. A.
J. Donald Macgregor, Walter K. Link, L. A. Smith
William Kennon McWilliams, Jr., New Orleans, La.
P. B. Leavenworth, T. R. Eskrigge, R. A. Steinmayer
Wayne Elden Moore, Ithaca, N. Y.
Charles Nevin, Katherine V. W. Palmer, G. D. Harris
Eugene Murrell Peeples, Jr., Houston, Tex.
Morgan J. Davis, Dwight J. Edson, George S. Buchanan
Colles Coe Stowell, Corpus Christi, Tex.
Oscar M. Hudson, O. G. McClain, C. C. Miller

FOR ASSOCIATE MEMBERSHIP

Richard D. Adams, Tulsa, Okla.
Oscar Hatcher, T. A. Clote, H. C. Arnold
Lundy Otie Allen, Oklahoma City, Okla.
Keith M. Hussey, E. L. Lucas, Carl A. Moore
Robert John Black, Chicago, Ill.
W. S. Levings, L. W. LeRoy, F. M. Van Tuyl
Robert Duane Brace, Houston, Tex.
L. W. LeRoy, J. Harlan Johnson, F. M. Van Tuyl
Dana B. Braislin, Jr., Los Angeles, Calif.
Stanley G. Wissler, Edward Blake Fritz, William A. Greenwalt, Jr.
Elliott Charles Bratt, Wichita, Kan.
Jackson M. Barton, Frank E. Lewis, Wendell S. Johns
Lyle Martin Brown, San Antonio, Tex.
L. A. Nelson, W. S. Strain, D. H. Cardwell
Richard Steele Bryson, Washington, Pa.
L. W. LeRoy, J. Harlan Johnson, F. M. Van Tuyl
Charles Edward Christmann, Golden, Colo.
L. W. LeRoy, J. Harlan Johnson, F. M. Van Tuyl
Carl U. Daniels, Jr., Tulsa, Okla.
J. Earle Brown, E. L. Lucas, Russell S. Tarr
Norman Samuel Domenico, Pasadena, Calif.
L. W. LeRoy, J. Harlan Johnson, F. M. Van Tuyl
Roger Max Dungan, Ventura, Calif.
Richard B. Haines, E. L. Lucas, Carl A. Moore
James Jack Ekstrom, Lawrence, Kan.
Robert M. Dreyer, C. G. Lalicker, Alfred G. Fischer
Glenn Marion Fedderson, Denver, Colo.
L. W. LeRoy, J. Harlan Johnson, F. M. Van Tuyl
Harry Robert Feder, Los Angeles, Calif.
J. E. Kilkenny, A. S. Holston, Jack M. Sickler
James Hendrie Griffith, Oklahoma City, Okla.
E. F. Schramm, W. L. Moreman, F. E. Wimbish

Jackson Horton Hammond, Long Beach, Calif.
Ursel S. Armstrong, George C. Kuffel, D. E. Taylor
Frank R. Hardin, Oakwood, Tex.
Travis J. Parker, Frederick A. Burt, William C. Rasmussen
James Maurice Harmon, Sherman, Tex.
Keith M. Hussey, E. L. Lucas, Carl A. Moore
Lorraine Elizabeth Hoyle, Shawnee, Okla.
Charles E. Decker, V. E. Monnett, F. A. Melton
James Powell Huie, Barcelona, Venezuela, S. A.
Louis Sass, E. L. Lucas, Keith M. Hussey
Neil Arthur Jackson, Haskell, Okla.
Carl A. Moore, V. E. Monnett, F. A. Melton
Charles Ripley Johnson, Jr., Decatur, Miss.
L. W. LeRoy, J. Harlan Johnson, F. M. Van Tuyl
James Eugene Keller, Ottawa, Kan.
C. G. Lalicker, R. C. Moore, John C. Frye
James B. Kite, Oklahoma City, Okla.
W. C. Kite, V. E. Monnett, Carl A. Moore
Harold A. Kuehnert, Evansville, Ind.
Edward C. Dapples, W. C. Krumbein, Isaac J. Pierce
Wayne Lebsack, Hays, Kan.
L. W. LeRoy, J. Harlan Johnson, F. M. Van Tuyl
Donald Paul Lowe, Franklin, La.
Donald L. Norling, C. H. Summerson, J. Osborn Fuller
Morad Malek-Aslani, Tehran, Iran
J. Harlan Johnson, Joseph A. Turner, F. M. Van Tuyl
Robert Lyon Marsh, Golden, Colo.
L. W. LeRoy, W. D. Mateer, F. M. Van Tuyl
Gloria June McFarland, Tulsa, Okla.
Charles E. Decker, V. E. Monnett, E. L. Lucas
John William Murchison, Jr., Galveston, Tex.
S. A. Lynch, Travis J. Parker, William C. Rasmussen
Charles Nelson Needham, Denver, Colo.
Warren O. Thompson, W. Warren Longley, John R. Hayes
Walter Hewitt Ortel, Golden, Colo.
L. W. LeRoy, J. Harlan Johnson, F. M. Van Tuyl
William Francis Prescher, Casper, Wyo.
Lynn W. Storm, G. W. Berry, Jed B. Maebius
Walter Thomas Prickett, Fort Worth, Tex.
Thomas B. Romine, Leo Hendricks, W. M. Winton
Gene R. Robinson, Jackson, Miss.
Wilbur H. Knight, H. V. Howe, Robert L. Geyer
Edward Stone Ryan, Trenton, N. J.
L. W. LeRoy, J. Harlan Johnson, F. M. Van Tuyl
Robert Charles Schwab, West Point Pleasant, N. J.
J. Harlan Johnson, L. W. LeRoy, F. M. Van Tuyl
Robert Russell Smart, Venice, Calif.
James E. Keenan, Cordell Durrell, John C. Crowell
Guy Merwin Steele, Jr., Norman, Okla.
Robert H. Dott, V. E. Monnett, Hugh D. Miser

Charles Eugene Sturz, Menlo Park, Calif.
Siemon W. Muller, Jay Glenn Marks, C. C. Church
William Hilliard Throop, Wichita Falls, Tex.
L. W. LeRoy, J. Harlan Johnson, F. M. Van Tuyl
Donald McKellar Van Sickle, San Marino, Calif.
J. Charles Miller, A. O. Woodford, Dion L. Gardner
Louis Aubrey Williams, Dallas, Tex.
James A. Waters, Wallace Ralston, Francis E. Heath
Kenneth Alvin Wood, Olney, Tex.
Raymond Sidwell, Charles A. Renfroe, W. I. Robinson

FOR TRANSFER TO ACTIVE MEMBERSHIP

Robert Lee Anderson, Denver, Colo.
L. Brundall, George R. Wood, V. Zay Smith
Edward Alricks Hamilton, Jasper, Tex.
Joseph T. Singewald, Jr., Harold E. Vokes, W. A. Cobban
Samuel Aubrey Kerr, Leduc, Alberta, Canada
W. P. Hancock, E. W. Shaw, John B. Webb
John Lewis Ponder, Everglades, Fla.
E. A. Murchison, Jr., W. C. Blackburn, Dunbar A. Fisher

ADDITIONAL APPLICATIONS APPROVED FOR PUBLICATION

(*Continued*)

FOR ACTIVE MEMBERSHIP

Ronald Eugene Beck, Alvin, Tex.
R. O. Dunbar, Robert P. Clark, A. J. Hintze
Herberta Van Pelt Branson, Tulsa, Okla.
J. R. McGehee, Carey Croneis, David M. Young
Dave Lynam Caldwell, Los Angeles, Calif.
Graydon Oliver, Glen M. Ruby, Harold W. Hoots
William Corliss Fackler, Fairbanks, Alaska
Stewart H. Folk, George A. Thiel, John L. Rich
Albert Everard Gunther, London, England
L. W. Leyds, E. A. Ritter, N. J. M. Taverne
Robert Bruce McCulloch, Denver, Colo.
Robert McMillan, L. Brundall, George R. Wood
Douglas Allan Pounder, Calgary, Alta., Canada
F. H. Edmunds, J. D. Weir, J. G. Gray
Howard William Reynolds, Jr., Burbank, Calif.
Elmer L. DeMaris, Hugh W. McClellan, Ian Campbell
Albert Thomas Rylands, Corpus Christi, Tex.
G. E. Archie, F. A. Nelson, Sherwood Buckstaff
Ray Bloss Vandeventer, Tulsa, Okla.
Frank R. Kittredge, Walter A. Ver Wiebe, W. Harlan Taylor

FOR ASSOCIATE MEMBERSHIP

Juan Jose Aguerrevere Porragas, Caracas, Venezuela, S. A.
F. A. Sutton, H. W. Thoms, K. F. Dallmus

John Abner Barnett, Jr., Roswell, N. Mex.
Leroy T. Patton, Raymond Sidwell, John A. Barnett, Sr.
Richard Walter Benner, Lewistown, Mont.
K. R. Parsons, John E. Blixt, K. K. Landes
Russell Cummings Cutter, Golden, Colo.
F. M. Van Tuyl, L. W. LeRoy, W. S. Levings
Joseph Robert Finerty, San Antonio, Tex.
James K. Rogers, Eldon Woodrow Langford, Harold G. Picklesimer
Dale C. Finley, Jr., Olney, Ill.
G. Gaddess, Kenneth G. Boling, Darsie A. Green
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EDWARD W. BELTZ is with the Arctic Contractors, Inc., which firm is developing Naval Petroleum Reserve No. 4 in Alaska. Formerly head of the Standard-Vacuum Oil Company geological operations in the East Indies, Beltz formerly retired from the service of the Standard-Vacuum.

RAYMOND LEIBENSPERGER, chief geologist and head of the exploration department of the Standard-Vacuum Oil Company, retired from active service on January 1.

The 30th annual meeting of the American Geophysical Union will be held at Washington, D. C., April 20–22.

JAMES G. DODD, recently with the Humble Oil and Refining Company, is employed by the Tennessee Gas Transmission Company.

THOMAS A. OGG, consulting geologist of Houston, Texas, died on January 16, at the age of 41 years.

ELWIN B. HALL, aged 57 years, died at Los Angeles, California, January 20.

At the annual business meeting of the Fort Worth Geological Society, Fort Worth, Texas, January 17, the following officers were elected: F. H. SCHOUTEN, president, Stanolind Oil and Gas Company; H. C. VANDERPOOL, vice-president, Texas Pacific Coal and Oil Company; THOMAS NICHOLS, secretary-treasurer, Rowan Oil Company.

ELMO W. ADAMS has left the employ of the Honolulu Oil Corporation, San Francisco, California, to enter private practice. He is succeeded by J. H. MCMASTERS as chief geologist.

THOMAS E. TURNER, geologist, formerly with the Magnolia Petroleum Company, has joined the Equity Oil Company and will be in charge of geological operations in its discovery area at Ashley Valley, Uintah County, Utah.

NOEL W. ENGEL has left Caracas, Venezuela. He is with the Superior Oil Company, Midland, Texas.

CLENON C. HEMSELL is geologist for the Cabot Carbon Company, Pampa, Texas. He was formerly with the J. M. Huber Corporation at Borger.

GLEN LEE CORRIGAN is head of the department of petroleum engineering at Louisiana Polytechnic Institute, Ruston Louisiana, after serving as associate professor in the department of mechanical engineering at the Oklahoma A. and M. College, Stillwater.

DAN E. BOONE is with the Aetna Oil Company, Houston, Texas.

R. V. BROWNE is in the employ of Petroleum Development, Ltd., Qatar, via Bahrein, Persian Gulf.

LAURO A. YZAGUIRRE is with Petroleos Mexicanos, Departamento de Exploracion, Calle Allende No. 120 Ote., Reynosa, Tamaulipas, Mexico.

J. WARREN SKRABANEK has left the University Lands to go with the Associated Engineers, Inc., Midland, Texas.

CHARLES DE BLIEUX, formerly with the Louisiana Land and Exploration Company, is a consultant at 902 Baronne Building, New Orleans, Louisiana.

The West Texas Geological Society, Midland, met on January 5, 1949, and elected the following officers: president, W. T. SCHNEIDER, Honolulu Oil Corporation; vice-president, RALPH D. CHAMBERS, Continental Oil Company; secretary, JESSE A. ROGERS, The Texas Company; treasurer, JOHN V. NORMAN, JR., Forest Oil Corporation.

PAUL WEAVER, president of the Association, delivered three lectures before the Geological Mineralogical Journal Club at the University of Michigan on January 13 and 14. His topics were "Frontiers of Petroleum Geology," "Formation of Marine Evaporites," and "Limestones in the Tertiary Along the Gulf of Mexico."

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Superior Oil Company, 510 K.F.H. Bldg.

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Noon luncheons, first and third Monday of each month at Wolf's Cafeteria. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka. Visiting geologists and friends welcome.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY

NEW ORLEANS, LOUISIANA

President - - - - - - - - - Fred S. Goerner
California Company, 1818 Canal Building
Vice-President and Program Chairman - - - - - - - - - - - - - - - M. N. Broughton
The Texas Company, 1500 Canal Building
Secretary-Treasurer - - - - - H. A. Nystrom
Schlumberger Well Surveying Corporation
452 Canal Building

Meets the first Monday of every month, October-May, inclusive, 12 noon, St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

THE SHREVEPORT GEOLOGICAL SOCIETY

SHREVEPORT, LOUISIANA

President - - - - - - - - Claude N. Valerius
Barnsdall Oil Company
427 Ricou-Brewster Building
Vice-President - - - - - Walter F. Hamilton
Gulf Refining Company
Box 1731
Secretary-Treasurer - - - - - - - R. T. Wade
Schlumberger Well Surveying Corporation
Box 92

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY

LAKE CHARLES, LOUISIANA

President - - - - - - - - - - W. B. Neill
Stanolind Oil and Gas Company
Vice-President - - - - - - Pete Haberstick
Atlantic Refining Company
Secretary - - - - - - - - James M. Whatley
Union Sulphur Company, Sulphur, La.
Treasurer - - - - - - - - - Bert C. Timm
Magnolia Petroleum Company

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - - - - - W. A. Kelly
Michigan State College
East Lansing
Vice-President - - - - - Ralph G. Hubman
The Texas Company
Mt. Pleasant
Secretary-Treasurer - - - - - B. T. Sandefur
Michigan State College
East Lansing
Program Chairman - - - - - - Gus Sanger
Pure Oil Company
Clare

Meetings: Monthly, November through May, at Michigan State College, East Lansing, Michigan. Informal dinners at 6:30 P.M. Papers follow dinner. Visitors welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY

JACKSON, MISSISSIPPI

President - - - - - - - - - - R. D. Sprague
Sinclair Wyoming Oil Company
Vice-President - - - - - - - E. T. Monsour
Consultant, Box 2571, West Jackson
Secretary - - - - - - - - - George W. Field
Cities Service Oil Company, 1407 Tower Building
Treasurer - - - - - - - - - Charles E. Buck
Skelly Oil Company, 100 East Pearl Building

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., The Creole Room, LeFleur's Restaurant, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY

ARDMORE, OKLAHOMA

President - - - - - - - Walter Neustadt, Jr.
Westheimer-Neustadt Oil Company, Box 974
Vice-President - - - - - - Richard G. Kendall
The California Company, Box 153
Secretary-Treasurer - - - - - - Frank Millard
Schlumberger Well Surveying Corp., Box 747

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA

OKLAHOMA CITY GEOLOGICAL SOCIETY

OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - - Robert R. Wheeler
Consultant, 1216 Petroleum Building
Vice-President - - - - - - - - L. R. Wilson
Carter Oil Company
1300 Apco Tower
Secretary - - - - - - - - - - John Janovy
Tide Water Associated Oil Company
918 Hales Building
Treasurer - - - - - - - - - Elwyn R. Owens
Phillips Petroleum Company

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon, Y.W.C.A.

SHAWNEE GEOLOGICAL SOCIETY

SHAWNEE, OKLAHOMA

President - - - - - - - - - Fred J. Smith
Sinclair Prairie Oil Company
Box 991, Seminole
Vice-President - - - - - - - Doyle M. Burke
The Texas Company
Box 1007, Shawnee
Secretary-Treasurer - - - - - Marcelle Mousley
Atlantic Refining Company, Box 169
Shawnee

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

OKLAHOMA

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - - - Jerry E. Upp
Amerada Petroleum Corporation, Box 2040
1st Vice-President - - - - - W. Reese Dillard
Consultant, Box 2204
2d Vice-President - - - - - Thomas E. Matson
Pure Oil Company
Secretary-Treasurer - - - - - - - Noel Evans
Consultant, 1510 Philtower Building
Editor - - - - - - - - - - John C. Maher
U. S. Geological Survey
Federal Building

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Lorton Hall. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

PENNSYLVANIA

PITTSBURGH GEOLOGICAL SOCIETY
PITTSBURGH, PENNSYLVANIA

President - - - - - - - - - John T. Galey
Independent, Box 1675
Vice-President - - - - - - - - W. B. Robinson
Gulf Research and Development Company
Box 2038
Secretary - - - - - - - - - James C. Patton
Equitable Gas Company
610 Wood St.
Treasurer - - - - - - - - - Sidney S. Galpin
Peoples Natural Gas Company
545 William Penn Place

Meetings held each month, except during the summer. All meetings and other activities by special announcement.

TEXAS

ABILENE GEOLOGICAL SOCIETY
ABILENE, TEXAS

President - - - - - - - Frank B. Conselman
Consulting Geologist
Vice-President - - - - - - - - J. R. Day
Pan American Production Company
Secretary-Treasurer - - - - Riley G. Maxwell
Consulting Geologist
Box 1939

Meetings: 2d Thursday of each month, 7:30 P.M., Wooten Hotel.

CORPUS CHRISTI GEOLOGICAL SOCIETY
CORPUS CHRISTI, TEXAS

President - - - - - - - - H. D. McCallum
Humble Oil and Refining Company, Box 1271
Vice-President - - - - - Norman D. Thomas
Pure Oil Company
Secretary-Treasurer - - - - - James D. Burke
Seaboard Oil Company of Delaware, Box 601

Regular luncheons, every Thursday, Terrace Annex Room, Robert Driscoll Hotel, 12:00. Special night meetings by announcement.

DALLAS GEOLOGICAL SOCIETY
DALLAS, TEXAS

President - - - - - - - - - John T. Rouse
Magnolia Petroleum Company
P.O. Box 900
Vice-President - - - - - - - - H. V. Tygrett
The Atlantic Refining Company
P.O. Box 2819
Secretary-Treasurer - - - - Gilbert P. Moore
Consulting, 501 Continental Building
Executive Committee - - - - - Edgar Kraus
Atlantic Refining Company
Box 2819

Meetings: Monthly luncheons and night meetings by announcement.

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

President - - - - - - - - - P. S. Schoeneck
Atlantic Refining Company
205 Manziel Building
Vice-President - - - - - - - - J. C. Price
Magnolia Petroleum Company
Box 780
Secretary-Treasurer - - - - - - G. C. Clark
Stanolind Oil and Gas Company
Box 660

Luncheons: Each week, Monday noon, Blackstone Hotel.
Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - - - F. H. Schouten
Stanolind Oil and Gas Company
Box 1410
Vice-President - - - - - - H. C. Vanderpool
Texas Pacific Coal and Oil Company
Box 2110
Secretary-Treasurer - - - - Thomas Nichols
Rowan Oil Company
Commercial Standard Building

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - - - - A. F. Childers
Gulf Oil Corporation, Box 2100
Vice-President - - - - - Hershal C. Ferguson
Consultant, 935 Esperson Building
Secretary - - - - - - - - - - R. R. Rieke
Schlumberger Well Surveying Corporation
Treasurer - - - - - - - - Mary L. Holland
Stanolind Oil and Gas Company

Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Rice Hotel. For any particulars pertaining to the meetings write or call the secretary.

TEXAS

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - - - - - J. J. Russell
Independent Geologist, 907 Staley Building

Vice-President - - - - - Joseph W. McDonald
Shell Oil Company, Inc., Box 2010

Secretary-Treasurer - - - - Ralph H. McKinley
Panhandle Producing and Refining Company, Box 1191

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Y.W.C.A. Evening meetings by special announcement. Visiting geologists and friends are cordially invited to all meetings.

SOUTH TEXAS SECTION AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
SAN ANTONIO, TEXAS

President - - - - - - - - - Marion J. Moore
Sunray Oil Corporation
1610 Milam Building

Vice-President - - - - - - Paul B. Hinyard
Shell Oil Company
2000 Alamo National Building

Secretary-Treasurer - - - - Maurice E. Forney
Atlantic Refining Company
1728 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

WEST VIRGINIA

APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P.O. Box 2605

President - - - - - - - - - W. B. Maxwell
United Fuel Gas Company, Box 1273

Vice-Pres., Northern Div. - - - Robert S. Hyde
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Kentucky-West Virginia Gas Co., Ashland, Ky.

Secretary-Treasurer - - - - G. L. Ballentine
268 Oakwood Road, Charleston, W.Va.

Editor - - - - - - - - - - W. T. Ziebold
Thomas Circle Road, Charleston, W.Va.

Meetings: Second Monday, each month, except June, July and August, at 6:30 P.M., Daniel Boone Hotel.

PANHANDLE GEOLOGICAL SOCIETY
AMARILLO, TEXAS

President - - - - - - - - - G. E. Hatton
Phillips Petroleum Company, Box 1761

Vice-President - - - - - - Robert F. Herron
Oil Development Company, 900 Polk St.

Secretary-Treasurer - - - - - Robert B. Totten
Sun Oil Company, Box 46

Meetings: Luncheon 1st and 3rd Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

President - - - - - - - - - W. T. Schneider
Honolulu Oil Corporation, Box 1391

Vice-President - - - - - Ralph D. Chambers
Continental Oil Company, Box 431

Secretary - - - - - - - - - Jesse A. Rogers
The Texas Company, Box 1270

Treasurer - - - - - - - John V. Norman, Jr.
Forest Oil Corporation, Box 1821

Meetings will be announced.

WYOMING

WYOMING GEOLOGICAL ASSOCIATION
CASPER, WYOMING
P.O. Box 545

President - - - - - - - - - Jed B. Maebius
Gulf Oil Corporation, Box 1971

1st Vice-President - - - - Emmett E. Schieck
Morton Oil Company, Box 1970

2d Vice-President (Programs) - Donald E. Edstrom
British-American Oil Producing Company, Box 620

Secretary - - - - - - - - - J. B. Headley, Jr.
Atlantic Refining Company

Treasurer - - - - - - - - - George L. Goodin
Petroleum Information, Inc.

Informal luncheon meetings every Friday, 12 noon, Townsend Hotel. Visiting geologists welcome. Special meetings by announcement.

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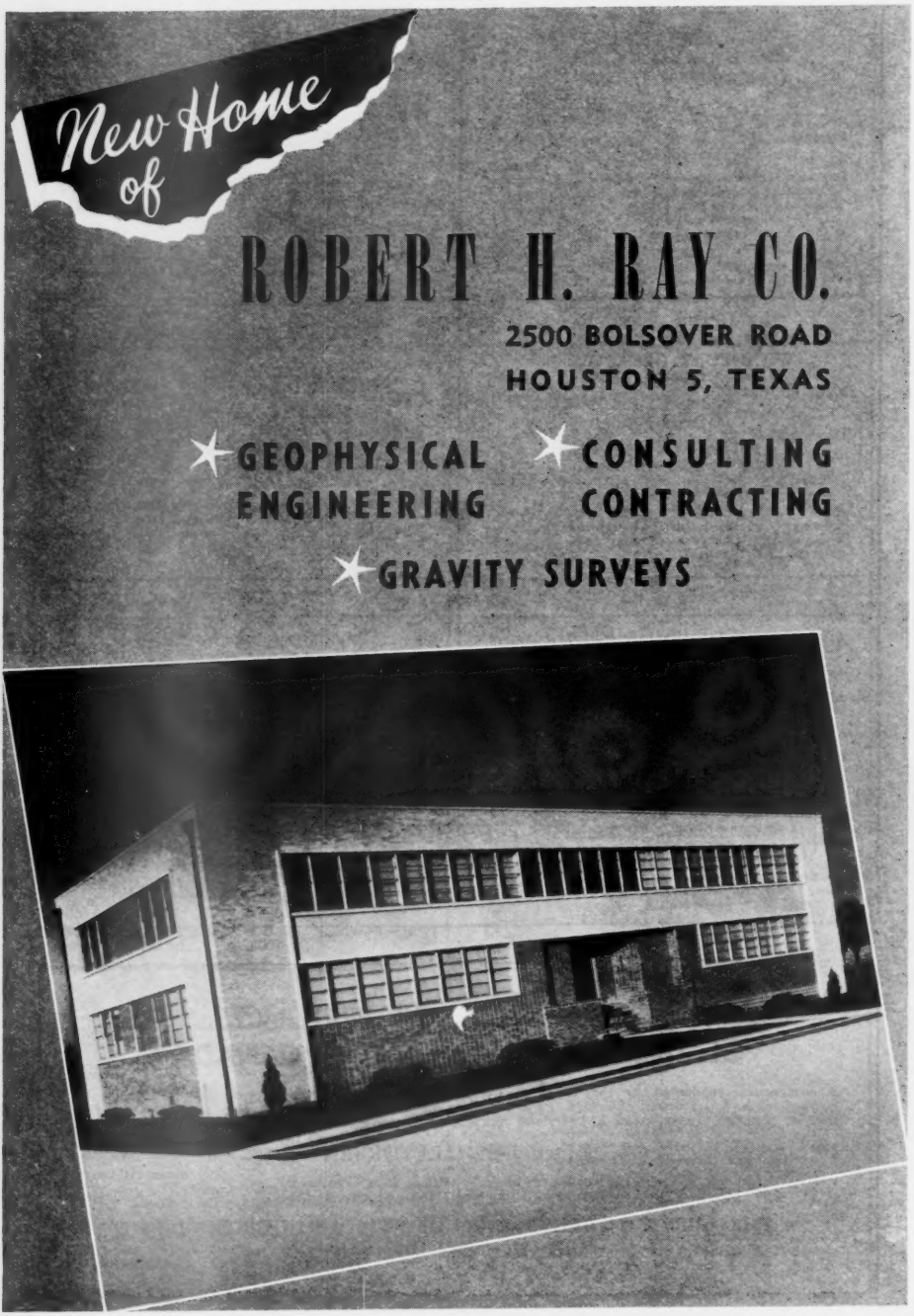
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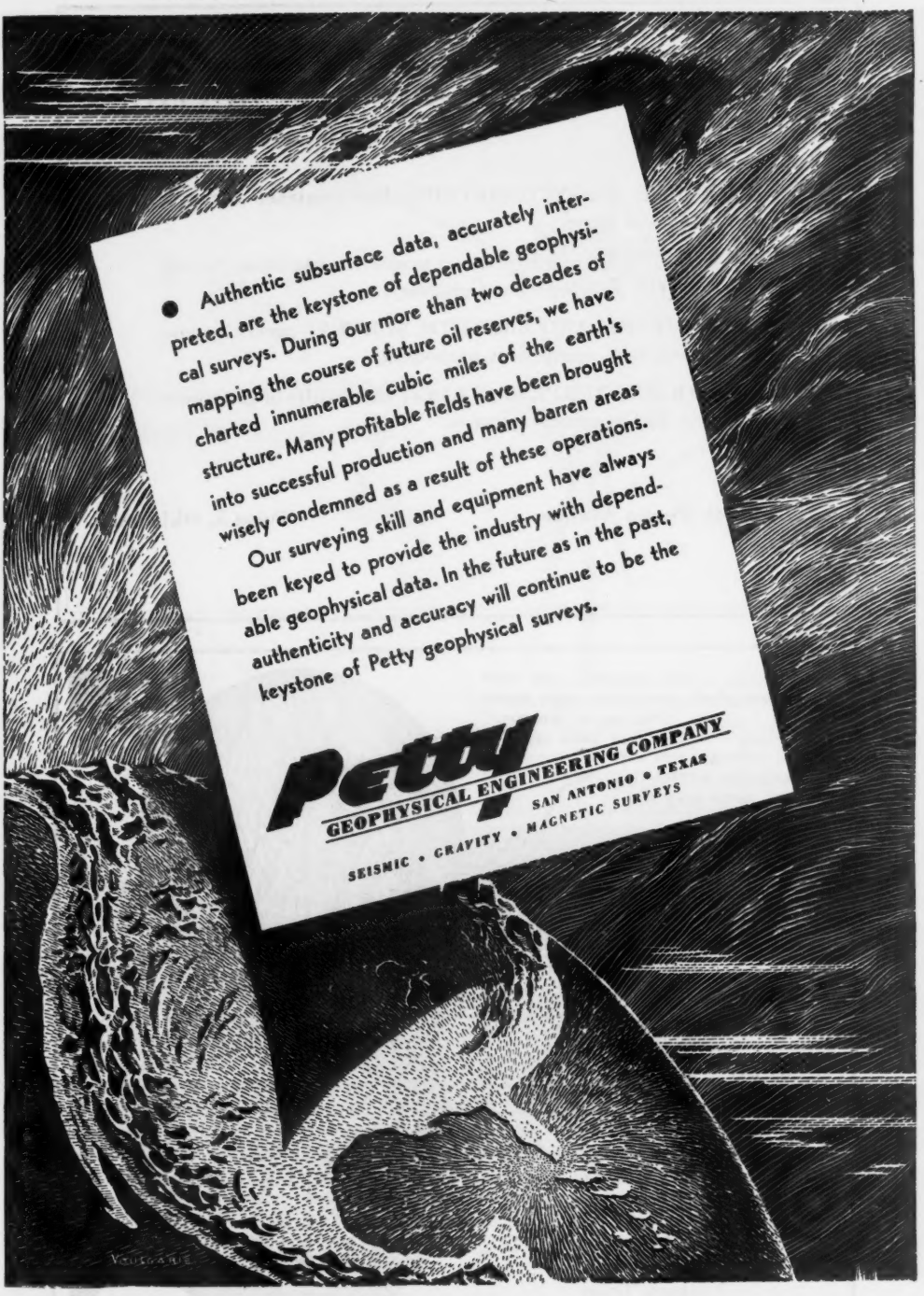
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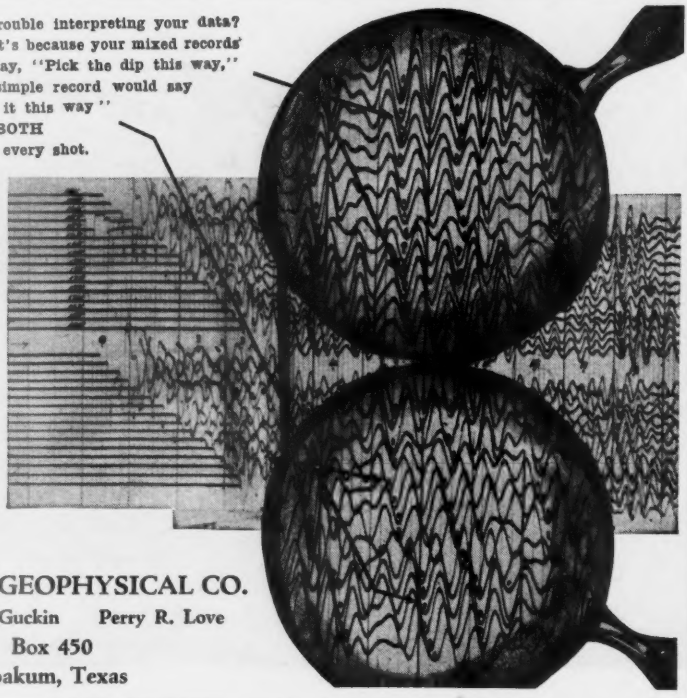

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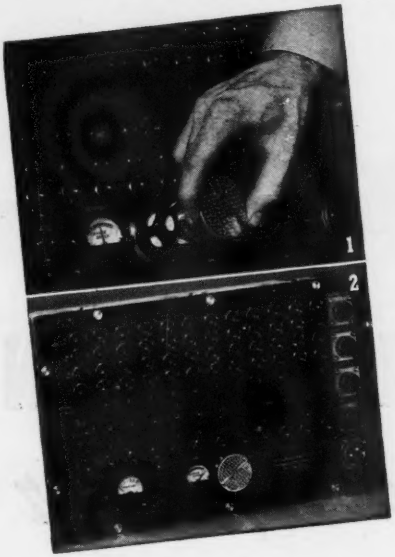

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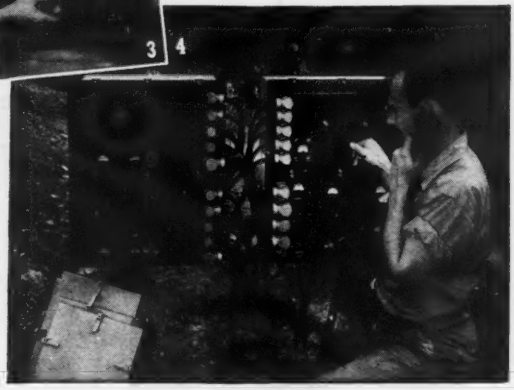

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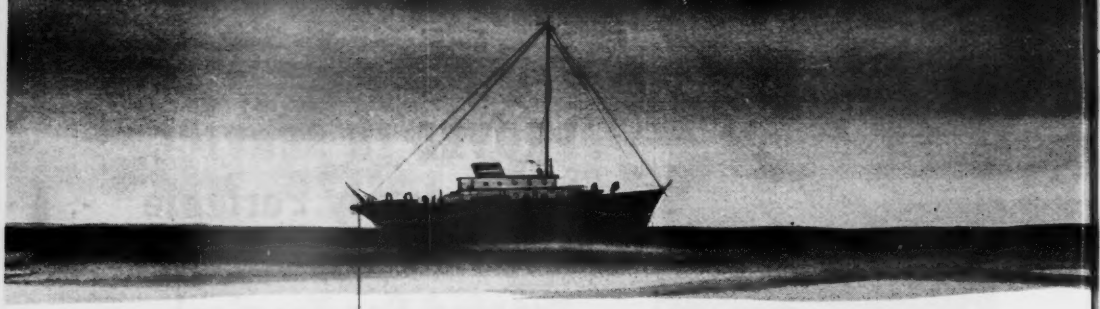

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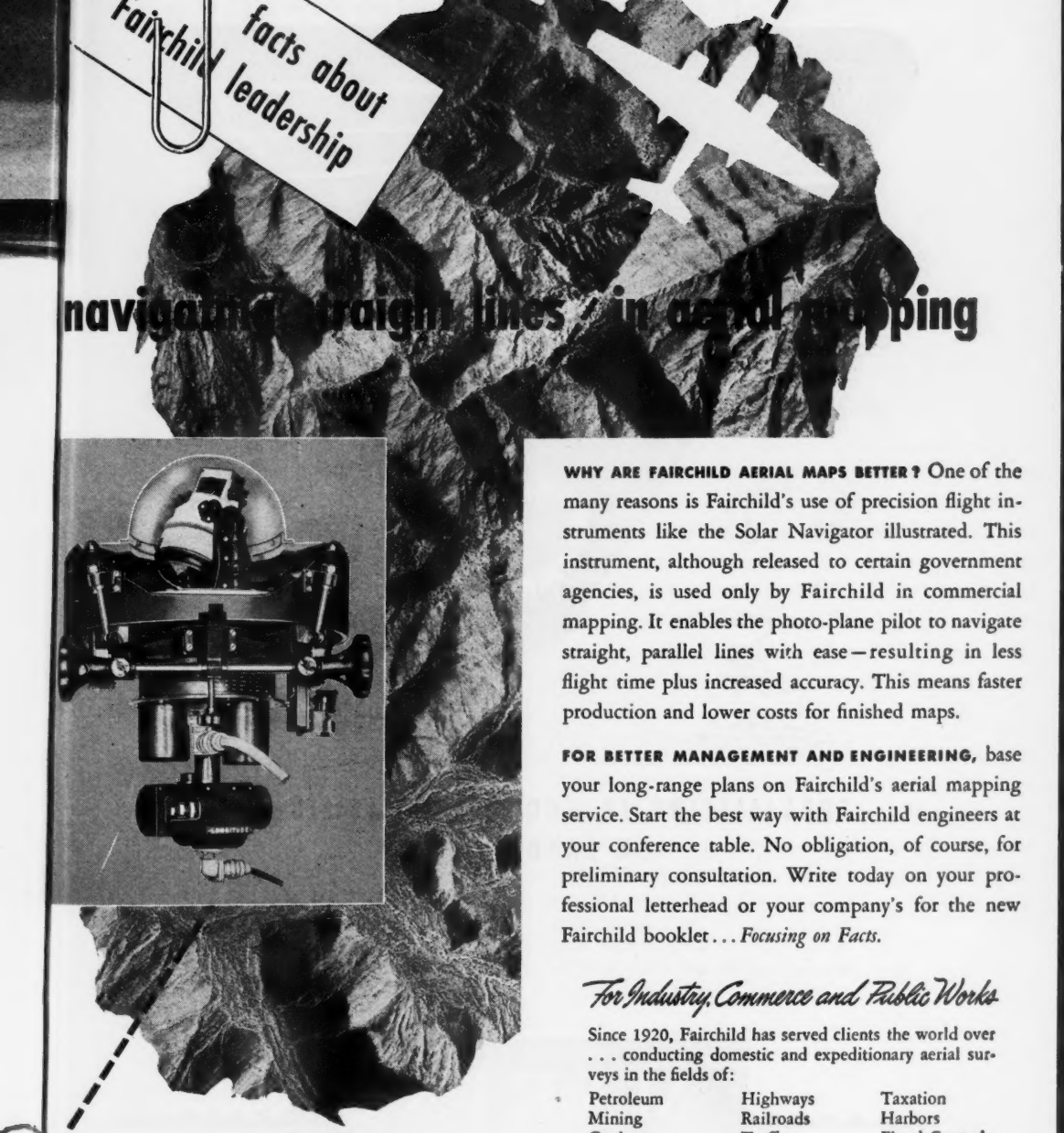

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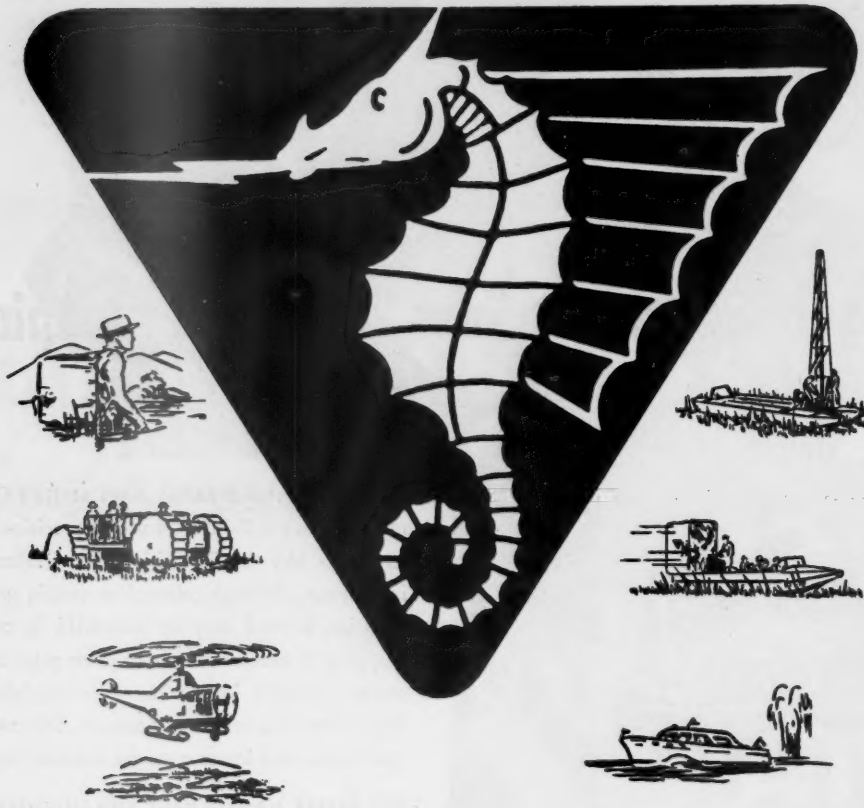

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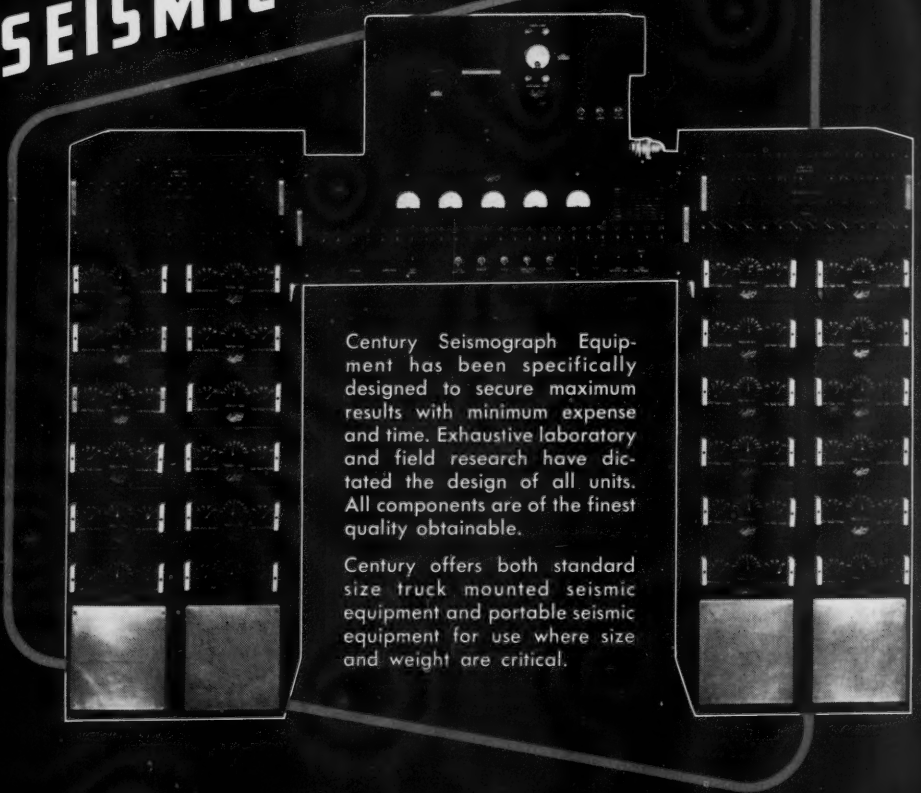

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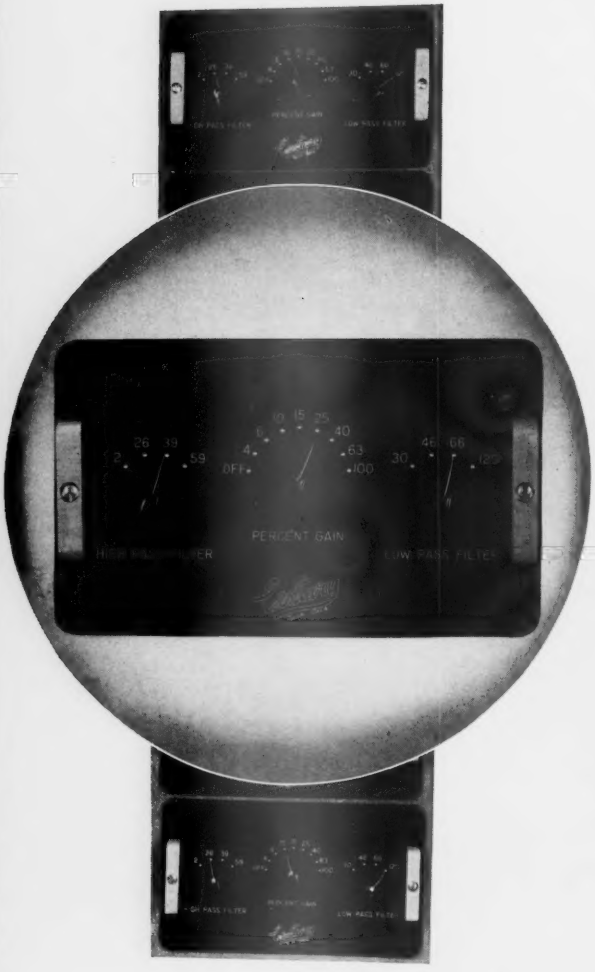

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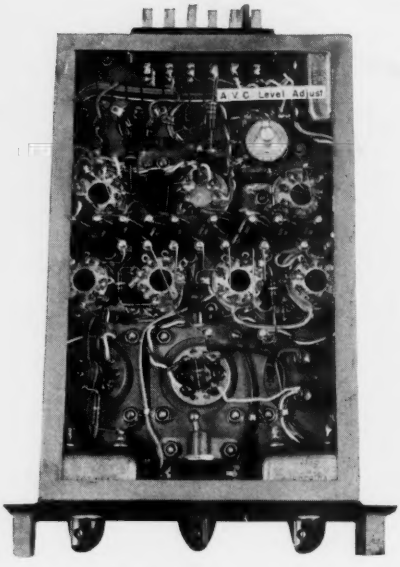

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"We ran a Combination Radioactivity Log, with a Collar Log, to define the stratigraphy and locate it accurately in reference to the collars. The log showed three porous zones in the Arbuckle, the lower one known to be water-bearing. The second zone was gun-perforated and squeezed for water shutoff. We perforated the top zone from collars, for production. IP was 1341 BOPD."

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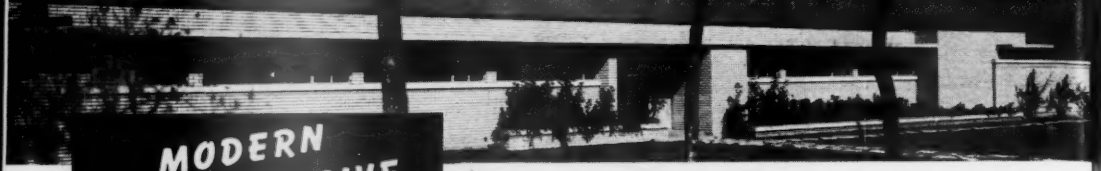

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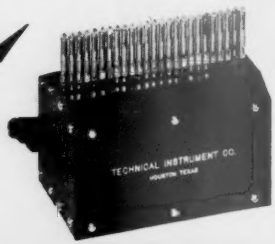

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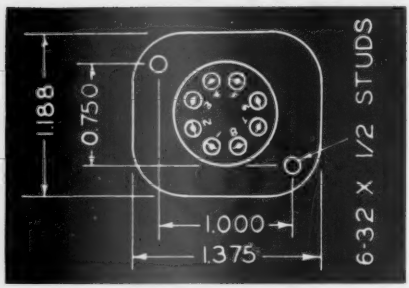

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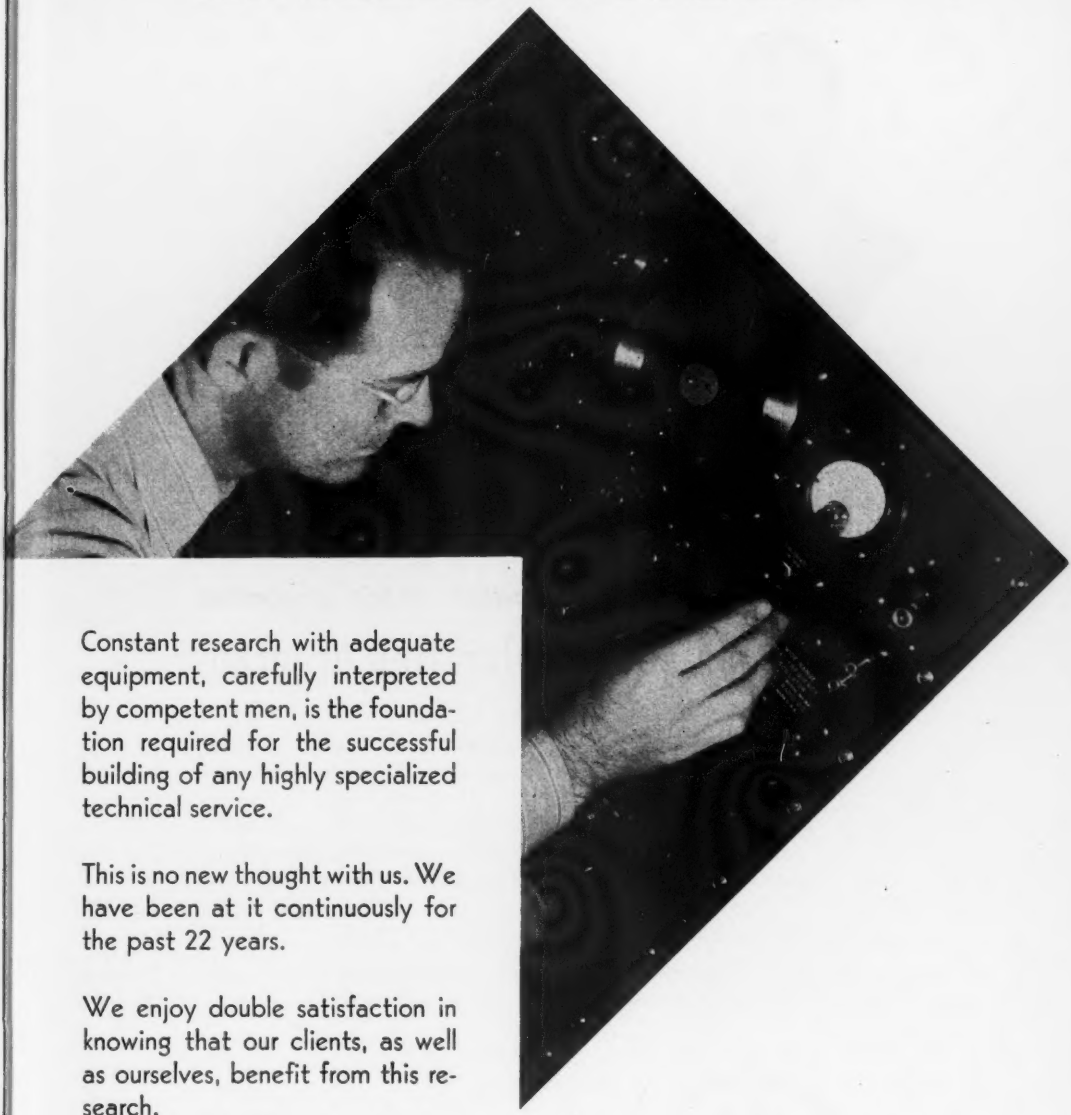

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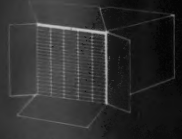

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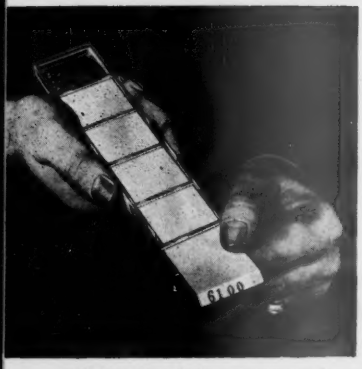

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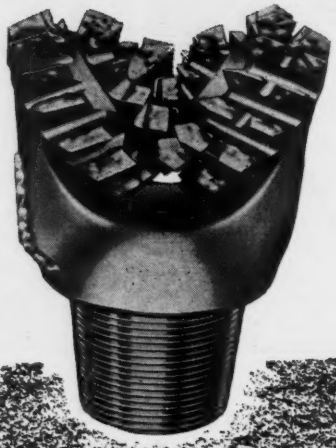

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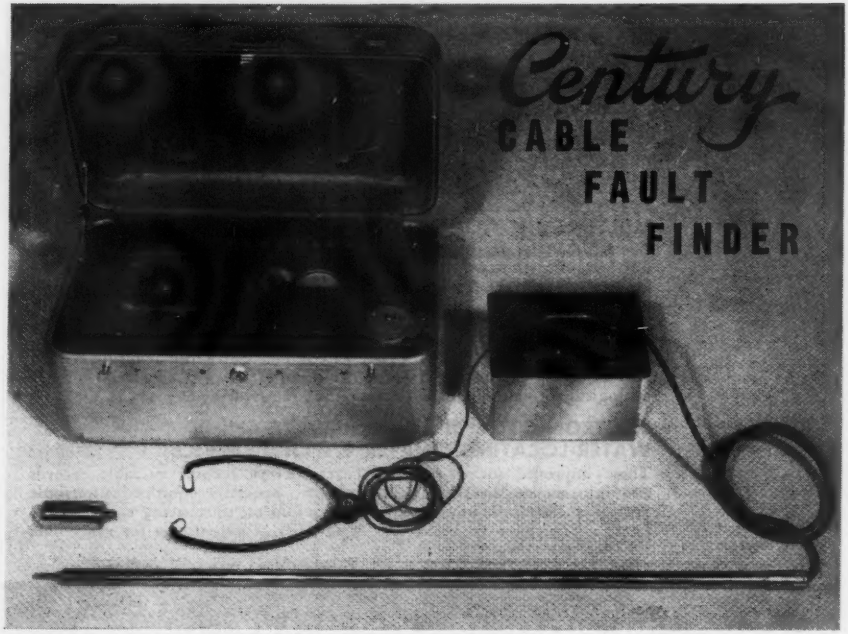

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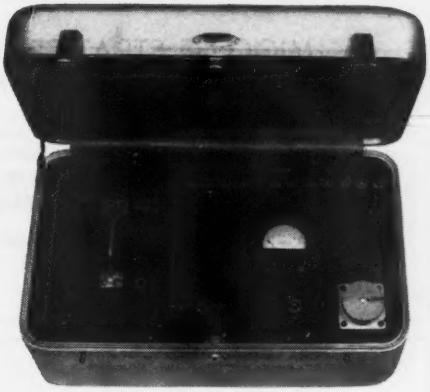

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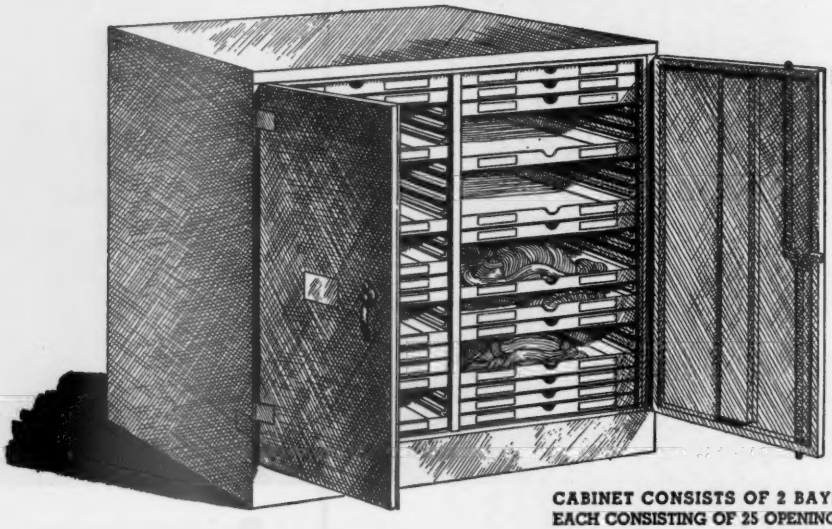

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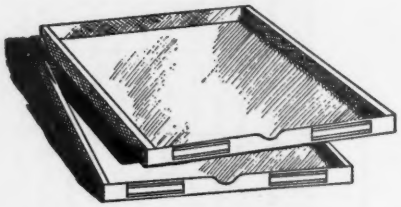

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*API Paper: 801-20E, March, 1944.

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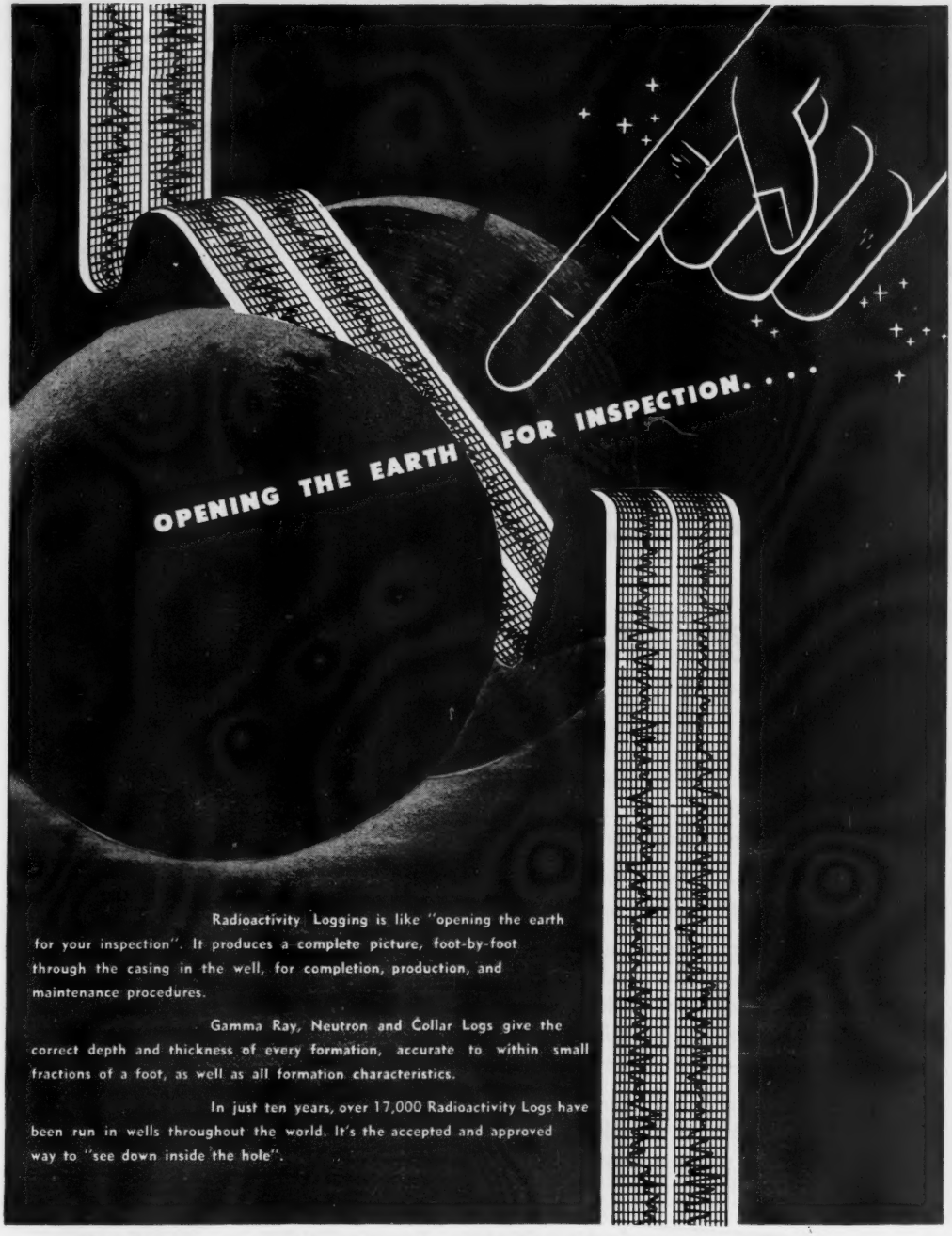

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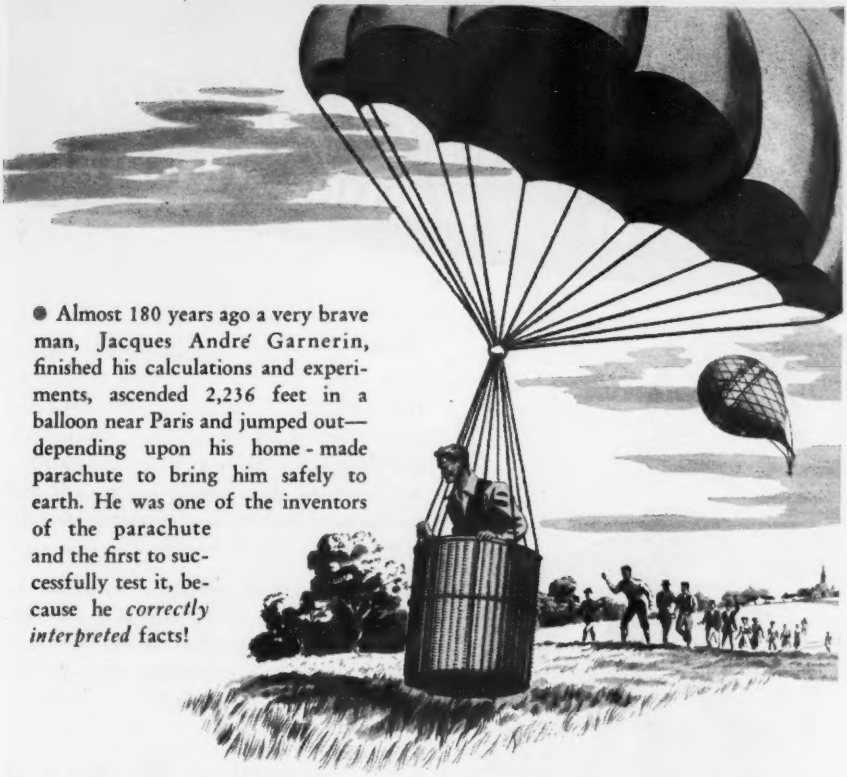

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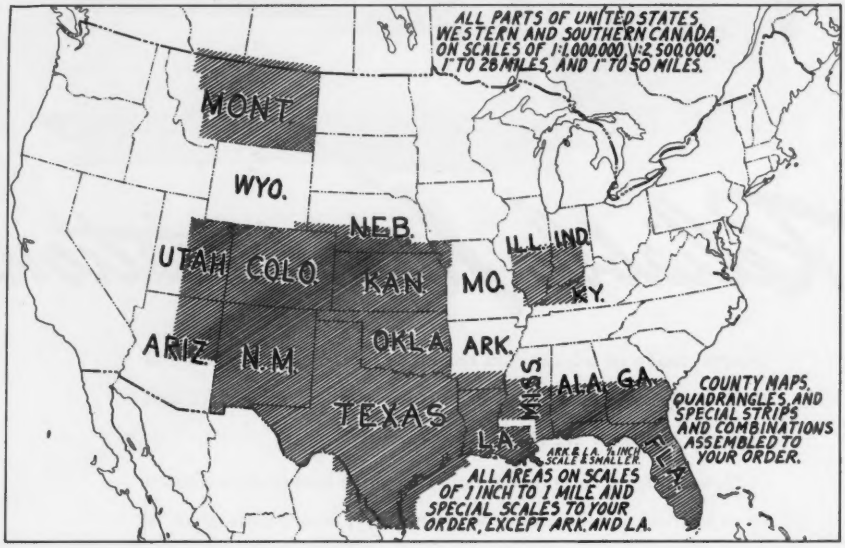

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